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BIOPLASM:

A

CONTRIBUTION TO THE PHYSIOLOGY OF LIFE.

BIOPLASM:

AN

INTRODUCTION

TO THE STUDY OF

PHYSIOLOGY & MEDICINE.

BY

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WITH NUMEROUS ILLUSTRATIONS.

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PREFACE.

In this little book an attempt has been made to determine and explain the nature of some of the most important changes which are characteristic of and peculiar to living beings. Technical terms have been as far as possible avoided. Many of the matters I have thought it desirable to consider are, however, complicated and intricate, indeed of a character not generally discussed in text books, and I fear that, in some instances, I have failed to render what I have tried to convey as clear and as intelligible as I desired. Most of the inferences I have drawn concerning very difficult questions rest upon actual facts of minute research, but I have ventured to speculate upon some matters which are at present beyond the sphere of observation.

The reader will probably admit that the first part of his task is not a difficult one, but as he progresses I fear he will find the book becomes more difficult to read. In the last four lectures some rather abstruse points in physiology have been brought under the student's notice, but the facts upon which the conclusions so far deduced have been based are recorded and explained.

Some of the investigations have been published in detail in memoirs that will be found in the Phil. Trans. of the Royal Society, the Trans. of the Microscopical Society, and elsewhere. The very last observations upon which I have been engaged have been included in Lecture XII, and four of the drawings in Plates XV, XVI, XIX and XX have been prepared to illustrate them.

How far the experiment of introducing the results of recent investigations into a little text book has been successful I must leave others to judge. My aim in this and other works has been not only to teach facts, but to encourage students to educate themselves for original enquiry in order that they may add new facts to those already known, and thus advance the department of natural knowledge they have selected for their life's work.

61, GROSVENOR STREET,
September, 1872.

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AN INTRODUCTION TO PHYSIOLOGY AND MEDICINE.

BIOPLASM.

LECTURE I.

Introductory—Of very Minute Living Particles—The First Stage of Being of every Living Thing—Form, Structure, Colour, Mechanism—Formation of the living from the Non-living—Of Living, Forming, Growing Matter, or Bioplasm—Protoplasm—Death of Bioplasm—The Crystal, the Magnet, and the Living Thing—Different kinds of Bioplasm—Origin of Bioplasm—Changes in Bioplasm, and of its Conversion into Tissue—Tissues at all Ages, in health and in disease, contain Bioplasm—Difference in structure not due merely to variation of condition.

1. Uninterrupted progress of Physiology. — No branch of natural knowledge exhibits such wonderful and uninterrupted progress as physiology. Not only is the superstructure being constantly added to and altered at the same time, but the very foundations are for ever being extended, improved, and renovated. No wonder, then, that, in our anxiety to add to existing knowledge, we sometimes misjudge facts and misinterpret phenomena. No wonder that observations regarded as very accurate at the time they were made, afterwards prove to have been erroneous, or that

the conclusions of one observer should be strangely at variance with those of another. Like the living things of which it treats, physiology is incessantly changing, and the true physiologist endeavours not only to add to existing knowledge, but so to add that further changes, which he knows are inevitable, may be made with the least possible derangement. In progressing, he desires to provide for further, and he hopes unceasing, progress.

2. Importance of good specimens.—Few things are more difficult than to observe and interpret correctly the mere structure of the tissues of man and animals. It is, therefore, all-important to obtain specimens which shall demonstrate clearly any new facts we think we have proved. Every effort has been made to illustrate by specimens the views I shall advance in these lectures: but the difficulties in the way of obtaining and preserving good preparations, which positively demonstrate at one view the facts upon which conclusions concerning structure and growth have been based, are so great that I scarcely think my efforts can be attended with complete success.

3. Magnifying powers employed.—The specimens which I shall have to describe have all been prepared upon the same definite plan, and have been preserved in the same medium. They have been examined under objectives magnifying from 50 to nearly 3,000 diameters.* In order that some idea may be formed of the degree of amplification of the one-fiftieth object-glass made for me by Messrs. Powell and Lealand in 1864, I may be permitted to mention that if it were possible to see a hair in its entire width under this power it would appear to be nearly one foot in diameter, and an object an inch in height would be made to appear as if it was 250 feet high.

4. Living and non-living.—I shall have to direct

* Proceedings of the Royal Society, January 19, 1865. "How to work with the Microscope," 4th edition, p. 286.

attention to some facts which have led me to conclude that certain phenomena manifested by part of the material substance of which all living things are composed, are peculiar to the living world; that between the *living* state of matter and its *non-living* state there is an absolute and irreconcilable difference; that, so far from our being able to demonstrate that the *non-living* passes by gradations into, or gradually assumes the state or condition of, the *living*, the transition is sudden and abrupt; and that matter already in the living state may pass into the non-living condition in the same sudden and complete manner; that, while in all living things chemical and physical actions occur, there are other actions, as essential as they are peculiar to life, which, so far from being of this nature, are opposed to, and are capable of overcoming, physical and chemical attractions. And I think the evidence which I shall adduce will prove conclusively that the *non-living matter* is the seat of the physical and chemical phenomena occurring in living beings, but that the *vital* actions occur in the living matter only. Moreover, we shall see that this living matter, which exists in every living thing in nature, can be easily distinguished from all matter in the non-living state.

3. Changes occurring during life.—I shall not confine myself to the demonstration of the structure of tissues which have been removed from the dead body, but shall endeavour to describe what probably takes place during life while these tissues are being developed, are growing, and are acting each in its own peculiar way. And if I fail in my attempt to give, as it were, an account of the life-history of a tissue, I trust I shall at least be able to assign a more definite meaning to the words "life," "living," "vital," &c., than has been done hitherto. It would be presumptuous in me to hope to place on a more sure foundation the science of the living, but I shall do my utmost to

rescue physiology, for a time at least, from being considered a mere subsection of physics.

6. Living particles.—It is difficult for the mind to realise the wonderful minuteness, the extraordinary number, and the almost universal distribution of particles of living matter. Not only are they found in and upon the earth and water, but the air teems with them, and is, as is well known, the medium by which some particles of comparatively large size and even of complex organisation are carried from the place of their formation to the seat of their development and growth. But of microscopic germs the air contains vast quantities differing entirely in their nature, their mode of origin, and in the results of their development. Living particles giving rise to various forms of microscopic fungi are wafted by currents of air into situations favourable for their development, and may become the active agents in every kind of fermentation and putrefaction, as has been proved by Pasteur. In the same way there is reason to think particles of living matter capable of giving rise to the most serious and fatal diseases of which man is the subject are carried to an organism which is in a state favourable for their reception and germination. No doubt millions of such living particles perish for every one that germinates. Some are much more easily destroyed than others. Certain kinds retain their vitality for a comparatively long time in a moist warm atmosphere, and it is not improbable that they may even grow and multiply, and perhaps produce particles differing from them in properties or powers. Some of these particles possess inherent motion, and it is probable that they climb, as it were, through still and moist air, just as amœbæ and certain other living particles are capable of climbing in any direction through water which is in a state of perfect rest. Minute particles possessing these inherent powers of active movement can insinuate themselves into the slight chinks

in fully formed tissues in every part of the body, and may easily make their way along the crevices between protective epithelial cells into the tissues beneath, and then through the thin walls of the smallest vessels into the blood.

7. Of obtaining living particles from air.—Very minute living particles may be obtained from the air in many ways. Perhaps the simplest process is to allow the vapour of the atmosphere to condense on the sides of a perfectly clean glass vessel filled with ice. The drops of water as they trickle down the sides are to be received into a conical glass, and any living particles entangled in the fluid can be detected upon microscopical examination with a sufficiently high power. In many instances two kinds of particles will be found—one soft, exhibiting movements in the fluid in which it is suspended; the other spherical or oval in form, comparatively firm, and possessing considerable resisting power. The first are often extremely minute, and so very transparent that they can only be distinguished from the medium in which they are suspended by very high magnifying powers, used with the greatest care and under the most favourable circumstances.

8. Two kinds of matter in a living particle.—Further examination enables us to demonstrate that the particles last spoken of are composed of matter in two different states: 1, a firm envelope closed at all points; and 2, a little delicate transparent matter within this, and resembling the material of which the first kind of particles seems to be entirely composed. I shall presently endeavour to show that these capsuled particles of living matter were not always so inclosed, and that the capsule was, in fact, formed in consequence of changes taking place upon the surface of a particle of living matter like the particles first referred to.

9. Two kinds of living particles.—Living things

in water, and living things on or in the ground, may in like manner be divided into (1) those which consist of living matter capable of moving in every direction, of dividing and subdividing, and invested only with a very thin layer of fluid or semifluid matter, and (2) those which are covered with a layer of a more or less resisting material, which interferes with or entirely prevents such movements of the living matter as have been referred to above.

10. An elementary part.—So also the elementary parts of which all the tissues and organs of man and all the higher animals are composed are found to consist of these two classes of particles—the first exhibiting the general characters already described, the last manifesting a great variety of form, structure, and properties, according to the arrangement, character, and composition of the external or enveloping matter.

The great difference between particles of apparently naked matter and particles enclosed in a thick envelope or capsule is but a difference of degree. The first, or apparently naked particles, are perhaps invested with so very thin a layer of soft and perhaps fluid formed substance that it follows the movements of the living matter, and is almost invisible; while in the last this formed matter has increased in thickness, and has undergone condensation, so as to interfere with the free motion of the living matter within, or, at most, to permit it only to move round and round within its prison wall. *Our investigation is therefore narrowed to the study of the changes taking place in the transparent living matter itself, and the production of the material upon its surface.*

11. First stage of being of every living thing.—Even man and the higher animals, as well as every other living thing, begins its life as a minute spherical particle, hardly to be distinguished from those minute particles of simple living matter suspended in the air (§ 6). The particle consists of colourless trans-

parent semi-fluid matter capable of moving in every part and in all directions. Man and animals, plants, fungi, monads, thus exhibit the same appearances, and the matter of which they consist exhibits similar characters. Each primitive particle was derived from matter like it which existed before it. It was simply detached from a parent mass.

12. Form, structure, colour, mechanism.—I hope to convince you that all form, colour, structure. mechanism, observed at a later period in the life-history of living things, result from changes in this primary structureless, colourless material. This primary matter of living beings which looks like mere jelly or a little clear gum or syrup, exhibits actions and undergoes changes unlike those occurring in every other kind of matter known to us. Although we can make many different substances exhibiting very remarkable properties, and machines capable of doing many kinds of work, and constructing wonderful things; no one has ever been able to obtain any chemical compound having the properties of this living speck, or any mechanism which acts as this wonderful transparent matter acts. The colourless, structureless matter, characteristic of and peculiar to all life on the earth. and in air and in water, is capable of moving in every part and in every direction. The movements are not such as are produced by vibrations communicated to the fluid or semi-fluid substance from matter in vibration in its neighbourhood, but the impulse proceeds from within the matter itself. The cause of the movement has not been ascertained. The facts will be more particularly described in Lecture IV.

13. Conversion of the non-living into the living.—Every kind of transparent colourless living matter takes up lifeless material which it *changes*. Certain elements of this are assimilated and converted into matter like that of which the living matter consists. After a time the matter which has become living under-

goes further change. It, or part of it, ceases to manifest its remarkable properties, and becomes resolved again into non-living substances, which are sometimes gaseous, sometimes fluid, sometimes solid. And very often the same living matter is resolved into substances in these three physical states. The solid matter that is *formed* may exhibit *structure*, or it may be *structureless*. It may be passive, or it may possess very active non-vital properties, as will be particularly discussed further on.

14. Living matter, or Bioplasm.—This wonderful matter to which I shall have frequently to refer in every part of this volume, *moves* and *grows*. Everything else in nature may *be moved* and *caused to increase* by aggregation—by particles being added to those already collected; but this alone of all matter in the world moves towards lifeless matter, incorporates it with itself, and communicates to it in some way we do not in the least understand, its own transcendantly wonderful properties. *The matter in question is living matter.* This matter, then, which is found in all living things, and in these only, is peculiar, and is to be distinguished from matter in every other state, be it *gaseous*, *fluid*, *solid*, *crystalline*, or *colloid*, *structureless* or *having structure*. This is the matter which *lives*. It may be correctly called *living* or *forming* matter, for by its agency every kind of living thing is made, and without it, as far as is known, no living thing ever has been made, or can be made at this time, or ever will be made. As the *germ* of every living thing consists of matter having the wonderful properties already mentioned, I have called it germinal matter; but the most convenient and least objectionable name for it is living plasma or *bioplasm* (βιος life, πλασμα plasm, that which is capable of being fashioned). Bioplasm is found in every tissue in every part of the living body as long as life lasts.

15. Protoplasm.—The matter which I have termed

forming, *living* or *germinal matter*, to which I have more recently given the name *bioplasm*, has been lately spoken of by others as *protoplasm*. And it has been hinted, though not definitely stated in print, that in my memoirs I had simply altered the name of matter which had been previously described by others. But such is not the fact as the most influential of my opponents well know. The word protoplasm would have been used by me had the term been restricted to the matter of the tissues, which I termed living or germinal matter, and which I showed, in my lectures at the College of Physicians in 1861, underwent conversion into formed matters, and was concerned in forming all tissue. But under the term protoplasm has been included, the contractile tissue of muscle, the axis cylinder of the nerve fibres, processes of nerve cells, and many other textures which undoubtedly consist of *formed material*, and are entirely destitute of the properties which invariably belong to my "germinal matter," or bioplasm.* Moreover, the nucleus and nucleolus were by many writers considered to be distinct from the protoplasm. On the other hand I showed that the nucleus and nucleolus were living. My bioplasm, germinal, or living matter therefore includes both nucleus and nucleolus as well as some forms of the protoplasmic matter of authors. Moreover, my paper on germinal matter had been written before the subject had been at all discussed, either on the continent or in this country, from the point of view I had taken up. Max. Schultze, who wrote after me, concerning the nature of the cell-wall, remarked that this structure had for me "only an historical interest," and objected to my conclusions.

16. Death of Bioplasm.—All bioplasm must die.

* But Prof. Huxley has given a yet wider signification to the word protoplasm, and makes it stand for almost anything organic. His new "protoplasm" may be *dead* or *living*, may exhibit *structure* or be perfectly *structureless*; nay, it may be even boiled or

By its death marvellous things are produced, and wonderful acts are performed. Every form in nature—leaves, flowers, trees, shells; every tissue—hair, skin, bone, nerve, muscle—results from the death of bioplasm. Every action in every animal from the first instant of its existence to the last, marks the death of bioplasm, and is a consequence of it. Every work performed by man, every thought expressed by him is a consequence of bioplasm passing from the state of life,—ceasing in fact to be bioplasm, and becoming non-living matter with totally different properties. To produce these results the death of the bioplasm must occur in a particular way, under particular circumstances, or conditions. These are often very complex, and as yet very imperfectly understood; but it will be my business to endeavour to elucidate them, as far as I am able, in this volume.

17. Products of the death of Bioplasm.—When the life of a mass of bioplasm of any kind is suddenly cut short, lifeless substances having very similar

roasted without ceasing to be protoplasm! The protoplasm of Huxley includes both my bioplasm and formed material, and although these things are to be distinguished from one another by so many essential characteristics, Mr. Huxley continues to affirm that both are protoplasm, though he is obliged to admit that one is "modified" protoplasm. More than twenty years ago, Huxley added to the confusion at that time existing on the cell theory, by affirming that the endoplast (my germinal matter) was unimportant, and but an accidental modification of the nucleus, which was sometimes altogether absent. He wrongly attributed formative properties to the *formed* lifeless periplastic substance, which is perfectly passive. But his new "protoplasm" is a compound to which it would be difficult to find anything analogous even in the annals of conjectural science. In that substance he has re-united the very matters he had before "differentiated," and has given rise to a further confusion of ideas by calling such things as white of egg protoplasm. Until, therefore, the term "protoplasm" is by common consent restricted to matter while it is living and growing, I must employ for the latter some other word which more accurately defines it, and "bioplasm" seems upon the whole the most convenient, as well as the shortest word that can be selected.

properties result. These substances belong to four different classes of bodies. One separates spontaneously soon after death. Another is a transparent fluid, which is coagulated by heat and nitric acid. The third consists of fatty matter; and, the fourth, comprises certain saline substances. When a mass of bioplasm dies it is in fact resolved into—1, *fibrin;* 2, *albumen*; 3, fatty matter; and 4, salts. These things do not exist in the matter when it is bioplasm, but as the latter dies it splits up into these four classes of compounds.

18. Bioplasm having died cannot live again.—Once dead, bioplasm ceases to be bioplasm, and is resolved into other things; but these things that are *formed* cannot be put together again to reform the bioplasm. They may be taken up by new bioplasm, and so converted into living matter; but the bioplasm that existed once can never exist again. All bioplasm must die, but *re-living* is, as far as we know, impossible, and scientifically is inconceivable.

19. A crystal may be re-crystallised.—A crystal may be dissolved in water and new crystals formed, but a particle of bioplasm can no more be dissolved and reformed than a man can be dissolved and re-crystallised. The difference between living matter and lifeless matter—between bioplasm and the things which result from its death, is absolute. The change from one state to another is sudden and complete.

20. A magnet may be re-magnetized.—The steel of which a magnet is composed can undoubtedly be *unmagnetized* and *re-magnetized* as often as we will; but the analogy which Prof. Owen has sought to establish between the magnetized steel, and the living organism is surely most fanciful. What two things are more unlike than a piece of steel and a dead organism, and what phenomena that we know of have less in common than magnetic phenomena and vital phenomena?

21. A dead thing cannot be re-vitalized.—Prof. Owen has remarked that "there are organisms (Vibrio, Rotifer, Macrobiotus, &c.), which we can devitalize and revitalize, devive, and revive many times!" But, the Professor in this sentence uses two words having different significations, as if they had the same meaning. To *revive* and *revitalize* are two very different things. That which is not dead may be revived, but a thing that is dead cannot be revitalized. The animalcule that can be *revived* has never been *dead*. The half-drowned man who *revives* has never died. The difference between the living state and the dead state is absolute, not relative. The matter from which life has once departed cannot be made to live again.

22. Different kinds of Bioplasm.—Since all bioplasm possesses certain common characters, and the bioplasm of one plant or animal produces formed matter of a very different kind from that resulting from another portion of bioplasm, we must admit that in nature there are different kinds of bioplasm indistinguishable by physics and chemistry, but endowed with different powers, flourishing under different circumstances, consuming different kinds of pabulum, growing at a different rate and under very different conditions as regards temperature, moisture, light, and atmosphere, possessing different degrees of resisting power, and dying under very different circumstances, having varying powers of resisting alterations in external conditions.

23. Origin of Bioplasm.—Concerning the origin of bioplasm, we have no knowledge or experience. Lucretius fancied that atoms came together under certain circumstances, and that thus living things or their seeds were produced. Some of the most advanced minds of the present day entertain a somewhat similar opinion. But both ancients and moderns base their doctrine on conjectures and their own peculiar

interpretation of facts. When these fail, they resort to dogma. The idea of spontaneous generation is being continually revived. New facts are advanced in its favour, but examination proves that the supposed new facts are not facts at all. Whether one primitive mass of bioplasm was caused to be, in the first creation, or five, or fifty, or whether thousands or millions rushed simultaneously or successively into being, is open to discussion, but the arguments in favour of the view that a minute mass of structureless bioplasm was the first form of living thing, are so overwhelming that they must carry conviction. The formation of tissues, organs, limbs, must have been a subsequent and very gradual operation, proceeding slowly by gradational changes according to certain laws. All evidence teaches us that from the first beginning of life, bioplasm has proceeded from bioplasm, and the formation of bioplasm direct from non-living matter is impossible even in thought, except to one who sets absolutely at nought the facts of physics and chemistry, and is perfectly blind as regards the ordinary phenomena of the living world continually succeeding one another before his eyes.

24. The changes of bioplasm and its conversion into tissue.—A mass of bioplasm exposed to certain special conditions which differ as regards heat, moisture, pabulum, and which vary with every kind of bioplasm, grows, divides, and subdivides into multitudes of masses. Each of these grows and subdivides in the same manner until vast numbers result. By these apparently similar masses of bioplasm, different tissues, organs, and members are formed. Some give rise to tubes which carry the nutrient fluid to all parts of the body. Some are concerned in taking oxygen from the atmosphere and giving up carbonic acid to it. Others separate materials resulting from decay, and convert these into substances which can be easily removed altogether

from the body. Other collections of bioplasm give rise to bone, to nerve, to muscle, and other tissues, while from others, organs so delicate as the eye and the ear proceed by gradual process of development, and convince us of the marvellous and inexplicable powers possessed by the formless bioplasm by which alone any of them could be formed. At length all the complex and elaborate forms of apparatus which make up the body of a living creature result. These excite our wonder the more thoroughly we study them, whether in what we call the lower or the higher creatures. These organs and structures perform their appointed work for the appointed time, decay, and are resolved into formless matters of interest to the chemist as well as to the anatomist and physiologist.

25. Different tissues in the body.—The body of a living animal is composed of many different tissues performing very different acts, and designed from the first to fulfil different purposes as proved by the fact that each working tissue has to pass through several stages of formation, during none of which does it work or serve any useful purpose. But these stages of inaction were necessary for its construction; and the ultimate form it was to take, and the duty it was to discharge, must have been determined from the first, when it was without form, and when no one could have premised either the form it was to assume, the work it was to do, or say why it existed at all.

Bone and flesh or muscle, and cartilage or gristle, cuticle, nail, and hair, nerve, fibrous tissue, are examples of different tissues. The tissues of the body change with age. The muscles of a young man are, weight for weight, more powerful than those of an old person or a young child. The tissues vary under different conditions. In health the same muscles and nerves will do far more work without fatigue than they

can perform at all when the person is out of health. The tissues of the aged are dryer than those of the adult, and the tissues of the infant are very soft and succulent. The tissues lose water and become firmer, tougher, and some of them more brittle as age advances, and the rate of nutrition and growth are modified accordingly.

26. Young growing tissues contain much water.—The succulent tissues of the young grow fast, but the dry textures of the aged shrink and waste instead of growing. The rate at which a tissue grows varies greatly at the different periods of life. All the different tissues are formed at a very early period of life—long before birth, at which time all the tissues exist though in a very soft and succulent state, and are easily injured, owing to their delicacy and want of firmness. This difference in the rate of growth at different ages is due entirely to the more ready access of pabulum at the early stage, as will be more fully explained in another lecture.

27. All organs come from bioplasm.—All the dissimilar tissues of a man are represented by the soft transparent bioplasm which is of the same consistence throughout and possesses the same character in every part. At the first the quantity of this bioplasm is so very small that it can only be seen through a microscope. It looks perfectly clear, and there is no indication of structure in any part. Yet the skin and bones and muscles and all the other organs ultimately come from it. It takes up food and increases. Gradually certain portions begin to form one tissue, and other portions another, and so on, until indications of all the different textures are to be made out, but being so soft and delicate their examination requires the greatest care.

28. Bioplasm in health and disease and at all ages.—The bioplasm in all living things undergoes change. The lifeless food we take becomes converted into bio-

plasm, and then this latter is changed into the lifeless nutrient materials which are taken up by the several forms of bioplasm which are concerned in the formation of the tissues. But bioplasm exists at all ages. It is to be detected in every tissue, be it healthy or diseased; simple or complex. Without it the tissue could not grow, and could not be repaired if it was injured. Without this it could not be said to *live*. In fact, the tissue that is *formed* is not living. The bioplasm only is alive, and the proportion of bioplasm decreases as the tissue grows old. At first the little speck of matter out of which the man or animal or plant is to be formed consists entirely of bioplasm, then soft temporary tissue appears, but the proportion of bioplasm to tissue remains very considerable for some time. Gradually, however, the tissue increases, and the proportion of living matter decreases, at last becoming so small that in many textures it does not amount to the $\frac{1}{100}$th part of the whole. In many cases this small particle of living matter dies, and then the tissue is incapable of further change. It is all dead. If injured it cannot be repaired. It is no longer *nourished*. It no longer performs its function. It may yet remain connected with the living body, but it is as dead as the lifeless dried up leaf that still clings to the living stem, though every vital connection has long since been severed.

29. Of difference in structure.—On taking a general survey of living things, the untrained student is impressed by the very wide and apparently irreconcilable differences in appearance and general characters exhibited by the multitudes of living forms familiar to him. A star-fish and an ox, a butterfly and a fish, an oak and a medusa, seem to differ from one another at least in as great a degree as any one of them differs from a stone, from water, or from air. But, on the other hand, after careful and prolonged study, the student becomes so familiar with the many points

in which these things resemble one another that soon it becomes difficult for him to believe that, different as all are from stones and inanimate objects of every kind, they are not very closely related to one another; and belief in this view may be strengthened by detailed research with the aid of very refined methods of investigation. The student will undoubtedly discover certain essential points in which all agree, and although the living things referred to differ from one another so enormously in dimensions, he soon finds out that the elementary parts of which the textures of all are composed differ comparatively slightly from one another even in size, while in general structure and appearance they are really much alike. Nor is any great difference in chemical composition to be demonstrated by chemical analysis. Moreover it can be shown that certain phenomena connected with the increase of tissues are common to them all, and when each is examined at a very early period of its formation, the resemblance between many dissimilar tissues is found to be so close that it might be inferred that all were identical at first, and that the ultimate divergence was due rather to the different circumstances under which each was evolved from the homogeneous than to any inherent peculiarities, properties, or powers of the bioplasm that evolved them. There is, indeed, a period in the development of every tissue and every living thing known to us when there are actually no *structural* peculiarities whatever—when the whole organism consists of transparent, structureless, semifluid living bioplasm—when it would not be possible to distinguish the growing moving matter which was to evolve the oak from that which was the germ of a vertebrate animal. Nor can any difference be discerned between the bioplasm matter of the lowest, simplest, epithelial scale of man's organism and that from which the nerve-cells of his brain are to be evolved. Neither by studying bioplasm under the

microscope nor by any kind of physical or chemical investigation known, can we form any notion of the nature of the substance which is to be formed by the bioplasm, or what will be the ordinary results of its living.

30. Variation in structure not due only to varying conditions.—And yet it would be childish trifling and mere playing with the facts of nature to assert, as some have done, that the character of the material produced and the properties not only of the tissue but of the bioplasm that produced it, depend in *all* cases upon the conditions under which life is carried on, merely because it has been found that alteration in the conditions under which life is carried on in *some* cases determines slight alterations in the results.

To deny inherent power in the original bioplasm is to deny without reason—to deny as a dogmatist or a bigot might deny; for the production of any formed material without bioplasm is impossible. Why or how bioplasm produces formed material we know not, but I have shown that the bioplasm dies—ceases to be bioplasm, whenever formation occurs—whenever structure is produced. And what are we to understand by the nature, or power, or property of living bioplasm? With what is it comparable? With the *properties* of non-living matter? Clearly not, for do not these belong to the matter itself, whether it be living or dead? *Living* properties are transferred from one particle to others with the utmost rapidity, but the very same matter may exist with or without its *vital properties*. By no alteration of conditions of which we have any conception can a given portion of matter which has once passed from the living to the dead state be restored to the living condition, and it is intolerable that we should be expected to receive the dictum that the form, properties, and action of living things are to be fully accounted for by the properties of the mere matter which enter into the composition of their bodies.

LECTURE II.

Examples of Bioplasm in Tissue—A young Leaf and its Bioplasm—Cartilage and its Bioplasm—Epithelium and its Bioplasm—Mucus and its Bioplasm—Movements of Bioplasm—Origin of new Centres—Bioplasm must be nourished—How Pabulum may be brought near to the Bioplasm—Organs for Introducing Food—Distribution of Nourishment—Rapid Growth of Bioplasm in the Adult and in Old Age—Rapid Growth of Bioplasm in Disease.

In the present lecture I propose to allude to the characters of bioplasm as far as they can be ascertained by low magnifying powers, and I shall allude to several points generally, which will be more particularly described in Lecture IV. It will be more convenient to postpone the consideration in detail of the wonderful phenomena of the bioplasm, until the student is acquainted with general facts more easily understood. Nevertheless those phenomena may be observed by any one well acquainted with the use of the higher powers of the microscope. They are of surpassing interest, although not to be explained by science, or accounted for by philosophy. I shall refer to a few simple textures containing bioplasm. If the student will place the structures alluded to under his microscope, he will be able to verify the few remarks that will be made in this place.

31. Examples of bioplasm in tissue. A young leaf and its bioplasm.—If a leaf bud be examined before any of the green colouring matter has been formed, the colourless bioplasm will be found occupying the cavities or little spaces in the tissue of which the

embryo leaf consists. The bioplasm is perfectly transparent and looks like pure water. The cavity in which it lies has been termed a *space* or *vacuole* which was supposed to be occupied by mere passive fluid. But the colourless material is living bioplasm, and so important that the walls of the spaces (cellar walls) could not have been formed except by its agency.

32. Cartilage and its bioplasm.—In a piece of cartilage or gristle it is easy to see the little masses of transparent structureless bioplasm, and distinguish these from the firm cartilage material which intervenes, and which has been formed by them. The structure of cartilage will be again referred to.

33. Epithelium and its bioplasm.—If a little of the soft matter be removed from the inside of the cheek, and examined under a magnifying power of two hundred diameters, it will be found to consist of numerous little particles (elementary parts or cells), every one of which contains in the central part an oval mass of living matter, around which is a firmer material that has been formed by the bioplasm, and was deposited layer within layer. Often very distinct concentric rings may be seen, owing to this mode of deposition. The younger the particles of epithelium* the larger is the mass of soft colourless living bioplasm in proportion to the formed material of which the outer part consists, and which has ceased to manifest vital properties or powers.

34. Mucus and its bioplasm—If a little viscid mucus be coughed up and examined under the microscope it will be found to be very transparent, and to exhibit streaky lines here and there. At short distances will be observed oval particles of transparent

* Epithelium, from ἐπί upon, and θάλλω to sprout, for it used to be supposed that epithelium grew or sprouted from membrane. Epithelium really is formed by bioplasm which sprang from preexisting bioplasm; the bioplasm existed before the membrane and therefore could not have sprung from it.

living matter or bioplasm, from which the mucus has been formed. These correspond with the masses of bioplasm of the cartilage and the epithelium, and the mucus with the formed material of these textures only. (See also §§ 79, 80, Lec. IV.)

35. Movements of bioplasm.—The oval masses of bioplasm in the mucus, like those in the tissues before referred to are alive, but the bioplasm being free to move in a soft medium, the remarkable movements can be actually observed, and may be studied without difficulty with the aid of a $\frac{1}{12}$th of an inch object glass, magnifying from six to seven hundred diameters as will be explained in Lecture IV. No material can be made artificially, in which such movements as these can be produced. This power of movement is invariably possessed by bioplasm. The rootlets of the plant extend themselves into the soil, because the living matter at their extremities moves onwards from the point already reached. The tree grows upwards against gravity by virtue of the same living power of bioplasm. In every bud, portions of this living matter tend to move away from the spot where they were produced, and stretch upwards or onwards in advance. No tissue of any living animal could be formed unless the portions of bioplasm moved away from one another. Portions of the bioplasm move and place themselves beyond the point already gained. The above are *vital* movements. (See § 80.)

36. Origin of new centres.—But besides these movements another phenomenon still more remarkable occurs in connection with bioplasm. In the very substance of the living matter itself, one or more spots make their appearance, arising as it were from within. They spring up and grow within the living matter. Absorbing nutrient material they grow and push outwards the bioplasm already existing. Again, new points of bioplasm may arise within these last. So that we may have two or three different centres of

growth, one within the other. The inmost of all is the last produced, and this is often found to be endowed with powers or properties different from those manifested by the bioplasm which preceded it, in which it was developed, which it is to replace, and which perhaps is to be entirely destroyed in order that the last, the newly developed bioplasm, may flourish for a time, and then give place to new centres which in their turn will appear within it. These little spots are known as "nuclei." The spot within the nucleus is the "nucleolus." (See § 85.)

37. Bioplasm must be nourished.—Every kind of living matter when it increases is said to be *nourished*. In order that the act of nutrition may occur it is necessary that the material constituting the *pabulum* or *nutrient matter* should be brought very close to the living matter. A part of the latter then moves towards the non-living pabulum. Bioplasm throughout its life tends to move away from its centre. Its particles seem to be impelled centrifugally towards any nutrient matter that may be near to it. Whether or not the non-living pabulum is taken up and converted into the living depends upon a number of circumstances which the living is utterly powerless to occasion, influence, control, or modify. But these external conditions being favourable and the pabulum being very near to the living matter, some of the latter is taken up by the living bioplasm, which communicates to certain of the non-living constituents its own particular properties or powers. Such essentially is the phenomenon of *nutrition*, which is universal in the living world, and which in fact consists of the taking up of the non-living matter by living matter and its incorporation with it. The non-living is made to live by the agency of that which is already living. The process of nutrition of an elementary part is more particularly described in Lecture V.

38. How pabulum may be brought near to the bio-

plasm.—The manner in which the pabulum is brought into very close proximity to the bioplasm, or into actual contact with it is very different in different cases. In man and the higher animals this operation is provided for by a highly complex apparatus deserving the most attentive study. So important is this to the well-being of the individual that, should any part of its intricate structure be impaired or its action modified in any great degree, serious derangement of the nutritive process results, and structural change of the most important kind in organs of the highest importance to the life of the complex being is occasioned. In the case of the simpler forms of life the pabulum is brought into the immediate vicinity of the bioplasm, so to say by accident. A breath of air, a drop of rain, may contain the pabulum which will provide for the free growth of some of the simplest organisms, which increase and multiply in so short a time.

39. Organs for introducing food.—In man and the higher animals most important organs minister to the introduction of pabulum into the intestine where multitudes of bioplasm particles are ever ready to take it up and grow and multiply at its expense. The introduction of aliment is not suffered to depend upon our reason and thoughtfulness. If the demand for food be not duly satisfied, the sensation of hunger is experienced, and when this becomes intense, every other desire, every other interest is in abeyance until the demand for food has been satisfied.

40. Distribution of nourishment.—The bioplasm having taken up the nutrient matter from the digestive tube undergoes change; a part of it dies, and some of its constituents, dissolved in water, pass into the blood which flows in channels close to it. The apparatus concerned in the *distribution* of the nutrient matter so dissolved to all parts of the body of man and the higher animals and plants, consists of tubes so communicating that the contained fluid may tra-

verse them freely and return to the same point. This is *circulation*. In the higher animals and man these tubes and certain organs connected with them, concerned in the propulsion of the fluid, are comprised under the head of *circulating organs*, and the fluid which continues to circulate in the vessels as long as life lasts is called the nutrient circulating fluid, or the *blood*.

The Heart.—The most important of these organs is the heart, which is a cavity, the walls of which are entirely composed of muscle, alternately becoming, contracted and relaxed sixty or seventy times in a minute, as long as life lasts. When the muscular tissue contracts, the cavity is much reduced in size, and part of its contents are forced out into a vessel continuous with it. The cavity enlarges again during the relaxed state of the muscular walls, and then it receives fluid instead of expelling it. This hollow muscular heart is connected with different sets of tubes or vessels. From one set it *receives* blood which it drives into the other set of tubes. The part of the heart which receives is called the *auricle* or *receiving cavity*, and this opens into the *ventricle* or *propelling cavity*. When the latter contracts, the blood is not driven back into the auricle, because some valves between the two cavities are instantly closed, and the whole force of contraction is spent in driving the fluid onwards into the large vessel or artery. Now, in man's heart, there are *two auricles* and *two ventricles*. This double heart is necessary for driving the blood through the vessels of the body generally, and through those of the lungs. The *right auricle* receives the dark blood from the *veins;* it then passes into the right ventricle, by which it is driven to the lungs, where it loses its dark colour from parting with carbonic acid, and acquires a bright red hue from gaining oxygen. After traversing the lungs, the blood is received by the left auricle from which it passes to the left ventricle. By

the contraction of this cavity, the blood is driven through the arteries of the system, and having traversed the minute ramifications or capillaries, it reaches the veins, and is at length poured into the right auricle, the point from which we first commenced to trace the course of the circulation.

But in all these highly complex operations a cardinal fact must not be lost sight of, viz., that bioplasm takes up the non-living pabulum and causes it to live, and that portions of this bioplasm, from time to time, undergo change and die, becoming resolved into compounds which did not exist before. The food is not simply dissolved and caused to pass into the blood as would be inferred from the description usually given, but millions of masses of bioplasm live and grow, pass through certain stages, and die, yielding up the products of their death, to be taken up by other bioplasm-particles, situated in the walls of the vessels and in the blood itself.

41. Rapid growth of bioplasm in the adult and in old age.—Although therefore for the most part the bioplasm of the tissues of the adult changes very slowly (§ 28), there are parts of the body in every complex animal and in man which, even in extreme old age, contain bioplasm, which grows and changes as fast as it does in early life. In the absorption of the nutritious matter vast multitudes of little naked masses of bioplasm take up, appropriate, and change the constituents of the food. Thus these little masses *grow*. After having reached a certain size little offsets project from different parts of them, and from time to time become detached. It is in this manner that the masses multiply.

42. Rapid growth of bioplasm in disease.—In disease the restrictions under which bioplasm grows in the tissues are in part removed, and growth takes place as rapidly as, or even more rapidly than it occurs in the case of the bioplasm of the embryo.

This is essentially what takes place in inflammation. The bioplasm takes up pabulum, and multiplies a hundred-fold. In the case of cancer, tubercle, and other "morbid growths," the bioplasm grows much faster than healthy bioplasm, and appropriates nutrient pabulum more readily.

43. Pus corpuscles.—It is through the increased growth and multiplication of normal bioplasm masses that the morbid "pus corpuscle" results. Pus is living bioplasm which grows and increases rapidly. Pus may result from the rapid growth of one mass of bioplasm, and in twenty-four hours, if nutrient matter be freely supplied, from one mass of normal bioplasm thousands of masses of morbid bioplasm or pus may result. Every one of these grows, gives off diverticula, and so the process of multiplication proceeds. It is also by very rapid growth and multiplication of bioplasm that disease germs are produced. These minute particles of bioplasm formed in one individual may pass through the air and gain access to the blood of another, grow, and multiply there, producing another case of "disease."

MICROSCOPICAL PREPARATIONS ILLUSTRATING LECTURE II.

	No. of diameters magnified.
1. Cartilage, common frog or newt, showing bioplasm and formed matter	215
2. Bioplasm and formed material, vegetable tissue ..	215
3. Cells or elementary parts, cuticle, newt. Old cuticle on surface. Young cuticle beneath	215
4. Cells or elementary parts of capsule of a seed ..	130
5. Cells or elementary parts of growing seed.. ..	215
6. Cuticle from the nose of the mole	215
7. Fat cells with small masses of bioplasm, newt ..	215
8. Bioplasm, growing fungus	215
9. Bioplasm forming buds or offsets of growing tissue at a very early period of development. Man ..	215
10. Bioplasm of fungus from a rotten apple	215
11. Large masses of bioplasm, newt	215

LECTURE III.

The Ovum or Egg—Of Development—Interstitial Channels—Vessels—Structures and Organs—Alimentary Canal—Glands for producing Solvent Fluids—The Blood for Nutrition—The Lungs for Respiration—The Liver for making Bile and Sugar, and altering the Blood—The Kidneys for forming and separating Excrementitious Matter—Cutaneous Glands for Secreting—Temporary Structures for use while the Permanent Organs are being formed—Skeleton—The Nervous System — The Muscular System — The Limbs—The Skin with Touch Organs—The Tongue —The Nose—The Ear—The Eye.

44. The Ovum or Egg.—The contents of the bird's egg are not directly converted into the tissues of the chick, but probably more than nine hundred and ninety-nine thousandths of the egg of the bird consist of pabulum upon which the developing embryo is to live. These constituents of the yolk, as well as the albumen or white of the egg, are taken up and changed by the minute speck of bioplasm which is the germ of the growing chick, just as food is taken up and appropriated by other forms of living bioplasm (§ 40). As soon as vessels are developed, these substances are taken up by bioplasm, just as pabulum from the intestinal canal in after life, and converted into blood. From this blood the various substances out of which the tissues are formed are taken. The wonderful growing point or spot which though so minute is the most important part of the egg, can always be seen if the egg be placed on its side and a portion of the uppermost part of the shell be carefully removed.

There is a white circular area, a little more than the eighth of an inch in diameter, which from being surrounded by the lightest part of the yolk, is always uppermost as the egg lies. In the centre of this is the minute mass of bioplasm which is the parent of all those from which the tissues are subsequently formed. Now in batrachia (frogs, newts, &c.) and fishes the part of the ovum which corresponds to the great bulk of the egg or the food yolk of the bird is very small, because the pabulum required during development is principally derived from the surrounding fluid, which is filtered by passing through a most delicate fibrillated tissue, which surrounds the ovum.* In mammalia the ovum is very minute, and consists almost entirely of bioplasm, which takes part in the formation of the germ. Its nutrient matter is supplied from a soft spongy tissue of the mother, specially formed for it. In this it is embedded. It imbibes its pabulum during the early period of its existence. As it grows it derives the substances to nourish it from the mother's blood (§ 58). The germ is not in any way dependent upon nutrient matter formed with it or soon after it, and inclosed with it in a confined space, as in the case of the eggs of birds, and also in those of the snake, tortoise, and many other members of the reptilia. The mammalian germ is in fact entirely and solely dependent upon the maternal organism for its nutrition. Moreover the eggs of most reptiles and some birds are hatched altogether without the assistance of the mother, and in few cases is this a necessary condition of development. The developmental changes proceed quite as regularly and as perfectly when the egg is exposed to artificial heat as when it is incu-

* This looks like the white or albumen of the bird's egg, but it is not albuminous, and consists of very delicate tissue, the meshes of which are occupied by water. It is a structure very like the vitreous humour of the eye.

bated by the animal heat developed by the maternal organism.

45. Of development.—At first, however, in all cases the minute particle of simple structureless bioplasm (§ 11), out of which a complex organism is evolved, gets its nourishment direct from the matter which surrounds it, whether this is enclosed with it from the first in a firm shell or supplied to it as required from the blood of the mother. The fit and proper substances are selected by the living matter which moves towards them (§ 37), takes them into itself, and converts these into more living matter like itself. Thus the primary living mass, from which springs every succeeding bioplast that takes part in the formation of the entire being, increases in size. It divides into two or more, and these grow and divide and subdivide until multitudes result. But as the collection of bioplasts becomes larger by subdivision and growth, it is obvious that the component bioplasts must be separated from the nutrient food by very unequal distances. Without some special provision this would involve unequal nutrition. The bioplasts upon the outer part or surface being in actual contact with the food, would grow quickly, whilst those towards the centre of the mass would increase very slowly, and would cease to grow at all in consequence of little or no nutrient material reaching them. They would be starved and die. Such a state of irregular growth does actually occur in the case of certain morbid (cancerous) structures. Owing to the circumstance of the irregular distribution of nutriment, in one part growth is most rapid, while in another situation the tissue actually dies from starvation, and is often invaded and consumed by new growth. In a very small space we may find in such a texture, 1, young actively growing matter; 2, fully formed tissue; 3, decaying texture; and,

4, the products resulting from changes occurring in tissue long since dead.

Interstitial Channels.—But in every embryo and in every normal tissue the equable distribution of nutrient matter is provided for and the flow regulated. As the growing embryo increases in size, intercommunicating spaces (lacunæ) and channels are formed here and there, and along these the fluids adapted for nutrition freely pass and meander in all directions, bathing, it may be, uniformly the growing bioplasts in every part, or distributing amongst them a gradually diminishing quantity of nutrient matter according as the distance from the nutrient surface increases. *See* Lect. V, § 117.

46. Vessels.—In the higher animals and in man actual tubes (vessels) are, however, developed for the purpose not only of conveying nutriment long distances from the one part of the body where it is taken up, and distributing it freely and equably to the several tissues and organs, but for removing products resulting from decay. Every part of the developing mass receiving its proper supply, growth may be as active or more active in those portions which are situated at the greatest distance from the point of supply than in those quite close to it. The vessels form a system of closed tubes composed of delicate membrane. These tubes are continually being traversed as long as life lasts by fluids holding in solution or in suspension everything that is required by the growing tissues which differ so remarkably from one another in structure, chemical composition, and physical and physiological properties. These tubes are everywhere so arranged that the contained fluid may circulate very rapidly and very freely. In this way every part of the growing mass is irrigated, but the growing tissue is not in contact with the nutrient fluid. The wall of the tube intervenes, but this is usually so very thin that solutions will pass through

it very quickly in both directions. And, indeed, a solution of substances adapted for the nutrition of the tissues is continually flowing through the wall of the vessels towards the bioplasm of the several tissues, while substances, resulting from the decay of tissues, also dissolved, flow in an opposite direction *from* the tissues through the vascular wall into the *blood*. The blood is driven through the vessels by the pump-like action of the heart into the interior of which the vessels open. (Page 24.)

47. Structures and Organs.—As the embryo increases in size and advances in development striking differences in character become manifest in different parts. Peculiarities of *structure* are observable, and the different structures perform very different offices. The vessels in which blood circulates are, however, distributed to them all, but the composition of the blood is altered both as regards what it gives up and what it receives, as it traverses the vessels distributed to the several parts.

48. Alimentary Canal.—In vertebrate animals an important tube is developed which is set apart for the reception and preparation of the food, and although this is not required during embryonic life, it must be *formed* so that it may be ready to do its work—to perform its highly important *function* when the newly formed organism comes into the world. Its characteristics in every stage through which it passes during its construction prove to us that the *form* it was ultimately to assume and the *work* it was to perform were, as it were, anticipated from the first. For months during its gradual formation it fulfilled no useful purpose whatever, and yet change succeeded change in pre-arranged order, until at last highly complex structures, adapted for certain definite purposes only, were evolved. The formation of these is complete, and they are ready to discharge their function at the time when their activity becomes necessary to

the maintenance of the life of the new being under the greatly altered conditions of existence.

49. Glands for producing solvent fluids.—In this digestive tube or cavity the undissolved food must be acted upon, so that it may be dissolved in water. The solution thus prepared is to be taken up or absorbed by the blood. Various secreting glands are therefore developed in connection with the digestive tube. These select certain materials from the blood common to the whole body, and convert them into fluids having very special and peculiar properties and endowments, which when fully formed pass away from the gland, being conducted by a tube or duct to different parts of the canal, where they become mixed with the food and exert their peculiar influence. Such are the *salivary glands* of the mouth, the *stomach glands*, the *intestinal glands*, the *liver*, the *pancreas*, and several others connected with the intestine which need not be particularised now—each taking part in a particular but very different operation. The saliva has the property of changing starch into sugar, and in a few seconds. The gastric juice dissolves meat and all forms of fibrin and coagulated albumen. The pancreas and the liver have to do with the digestion of fatty matter, and the secretions of the intestinal glands exert yet different actions. From the digestive tube nutrient matter is taken up by masses of bioplasm, and by these passed on, as it were, to blood-vessels, as has been already stated in § 40. The newly introduced pabulum is converted into blood by bioplasm, and this blood is driven through the minute vessels (capillaries) in every part of the body. Through the walls of the capillaries, fluid transudes, which is taken up by the bioplasm of the several tissues lying outside the vascular canals. In a similar manner it is probable that the bioplasm in the walls of the vessels and the bioplasm in the blood take up the matters resulting

from the disintegration of tissues and return them in a modified form to the blood.

50. The Blood.—The blood is the fluid from which the material constituting all the tissues of the body is derived. It exists at a very early period of development, before the tissues exhibit their structural character or special properties. The food we take is not directly converted into tissue, but into blood. Neither are the substances resulting from the breaking down of tissues at once converted into the materials which are excreted from the body by the lungs, liver, kidneys, skin, and intestines, but into blood. The order of change therefore may be represented thus 1. *food;* 2. *blood;* 3. *tissue;* 4. *products of decay;* 5. *blood;* 6. *excreted matter.* But if we take more food than our body requires, the excess, after having been converted into blood, is excreted without being first converted into tissue. This excess is not only useless, but its excretion may overtax our organs and damage them very seriously, particularly if they are not of large size and in thoroughly good order. Excess of food is not unfrequently in this way the cause of derangement of certain important organs, particularly the liver and kidneys, and may occasion early death. The blood is being continually renovated by the conversion of food into it. The food does not pass directly into the blood-vessels, but certain of its constituents are selected and absorbed by the living matter of the walls of the blood-vessels, and by that of the blood itself. In this way the food is changed and converted before it becomes blood.

51. Bioplasm of the Blood.—The blood is not a mere solution of food matter, but contains many living particles in suspension, which circulate with it, and grow and multiply, and arrive at maturity and die, becoming resolved into matters which are dissolved in the liquid which permeates the walls of the vessels, and is applied to the nutrition of the

growing tissues. The living particles of the blood vary greatly in size and number, according to the quantity and nature of the food, and a number of circumstances. There exists suspended in the fluid portion of the blood, multitudes of living particles, so minute that they cannot be seen by ordinary magnifying powers. These play a highly important part in the phenomena of the body. I described these minute particles of bioplasm in 1863.*

52. Red Blood Corpuscles.—Besides the particles of living matter, the blood of all vertebrate animals contains multitudes of small, soft, semi-solid particles of a red colour, which give to blood its characteristic appearance. In health, in warm-blooded vertebrata, these are very numerous, and are known as the *red blood corpuscles.* The fluid in which these little corpuscles are suspended is by them as it were much divided, a small portion being smeared over each individual red blood corpuscle. As these are kept by the propelling power of the heart in continual motion, the equable composition of the blood is maintained, and a small quantity of the fluid portion is smeared upon the wall of the vessel, and upon the bioplasm of the capillary which projects into the cavity, as the red blood corpuscles one after the other are driven into contact with it. So perfect are these arrangements in their working, that irregularities in the distribution of the fluid are corrected or compensated while there exists also provision for ensuring that the general composition of the blood shall remain constant, in spite of its undergoing most important changes in every part of its course.

53. Liver for making Bile and altering the Blood.—The liver, unlike the other important secreting organs developed in the embryo, attains functional importance at a very early period of life. Long before

* "On the Germinal or Living Matter of the Blood." Trans. Mic. Soc., Dec. 9, 1863.

birth, and long before most of the important tissues of the body exhibit their characteristic structure, some time before the intestine into which the secretion of the gland is poured, is fully formed, the liver not only possesses the structure it exhibits permanently, but it performs its work, and probably in much the same way as during later periods, when the conditions under which life is carried on are so very different from what they are during development. In short, the liver seems to be formed as a permanent organ almost from the very first, and fulfils two very important functions. By its agency, certain matters are separated from the blood, and converted into two distinct classes of substances, one of which is returned to the blood soon after its production, while the other is carried away from the gland and poured into the intestine. The material formed by the liver and returned to the blood is *sugar*, and that which is carried to the intestine is *bile*, of which part seems to be effete, and at last escapes from the bowel, while part is re-absorbed in an altered state by the intestinal capillaries, and mixed with the blood.

54. Lungs for respiration.—In another part of the developing being organs are formed which are destined to effect, without a moment's interruption, most important changes in the blood, from the instant after birth until death. These organs are the *lungs*, and as the blood traverses the capillaries it takes up oxygen and gives off carbonic acid and other constituents.

55. The Kidneys for secreting.—The *kidneys* contain bioplasm which selects various matters from the blood. It undergoes change, and becomes resolved into certain constituents, which pass away from the body altogether. These glands attain their perfect form slowly, and are preceded by temporary organs.

56. Cutaneous glands.—Glands are also found in connection with the skin, whose office it is to

remove from the blood certain deleterious matters, and discharge them in the form of perspiration and sebaceous oily matter.

57. These organs for the most part inactive during embryonic life.—But to the embryo, with the exception of the liver, the above organs are comparatively useless. They are being formed for work, but are as yet incapable of work. Nevertheless, the work that will in the future be discharged by them must be performed somehow. Food must be introduced though the digestive organs cannot be used, oxygen must pass into, and carbonic acid out of, the blood, though the lungs cannot act: and various deleterious excrementitious materials must be got rid of, though the glands being formed for this special purpose are inoperative.

58. Temporary organs.—There is an arrangement specially to fulfil these duties for the time. Various temporary structures which are discarded at birth, or are gradually destroyed and removed after birth, perform, and in a most perfect manner, the highly essential operations which are afterwards carried out in a very different way. From the blood of the mother is taken the nutrient matter from which the blood found in the vessels of the growing embryo is prepared, and into the maternal blood some of the products of decay are discharged. It likewise gives oxygen to the embryo's nutrient fluid, and receives from it carbonic acid, which is ultimately excreted by the maternal respiratory apparatus.

59. The Skeleton.—The firm internal bony skeleton. characteristic of all vertebrate animals, and which supports all the other tissues of the body, is developed at a time when no such support is required. When the skeleton is first formed, it is as soft as the soft tissues, and it only gradually acquires firmness as the form of the several bones manifests itself. In the soft state it is quite useless for the purposes for which

it is required, and a further important change is necessary. The soft transparent tissue, of which it is in great part composed, becomes infiltrated with earthy matter, consisting principally of phosphate of lime and magnesia, and this process continues in progress even until after the animal has attained its perfect form. But the *bone*, which is first produced, is only a temporary structure, and far too weak and brittle for the requirements; for, besides hardness, bone must possess elasticity in some degree, so that it may stand a sudden blow without breaking. The whole of the bone first formed is, in fact, removed, and gradually replaced by a firmer, harder, much stronger, and more elastic and more permanent tissue, very different in structure from that which preceded it. But this more perfect type of bone tissue could not have been developed at the first. Its production involved a number of preliminary changes useless to the economy until the whole series was fully completed. Nor from the structural characters of the early tissue would it have been possible to premise the structure assumed by the permanent bone. Here, as in so many other cases, we see highly elaborate and complex structure anticipated, as it were, at a time when its actual production would have been impossible. It is therefore certain, that the most thorough knowledge of the properties of the matter of a living being would not enable us to form any conception of the form the tissues were ultimately to take, or the office they were to discharge.

60. Nervous tissues.—The nervous tissue is developed *pari passu* with many other textures of the body. And of all the tissues it undergoes the most remarkable progressive changes. The relation of some of the most important parts of the nervous system is being continually altered, and yet without any derangement of function in any portion of it. Nerve tissue comes into very close relationship with

many other textures, and reaches the utmost confines of the system. Its structure is elaborate, and its work in some cases never ceases for a moment as long as life lasts. Unlike every other tissue in the body, the nervous tissue exhibits uninterrupted continuity of texture. There is not a thread in any part of the nervous system the tissue of which is not connected with the nerve tissue of other parts,—which is quite disjoined from other threads and nerve matter.

61. The muscular tissue is to be detected at a very early period, and two different kinds of tissue having contractile property can be distinguished in man and the higher animals. The movements of one being under control of the will, through the intervention of nerve tissue is termed *voluntary muscle*, the other, although equally under nervous control, is not directly influenced by the will, and indeed contracts without our being conscious. This is called organic or involuntary muscle. Such a division is, however, not strictly accurate, and it is better to speak of these two kinds of muscular tissue respectively as the *striped* or *transversely striated muscle* and the *unstriped muscle.* Although examples of the first are usually under voluntary control, and therefore properly termed voluntary muscle, instances are not wanting of striped or transversely striated muscle which is not under the influence of the will. At an early period of development the striped muscle resembles the non-striated in general appearances as will be described when muscular tissue comes under consideration.

62. The skin.—As would be supposed, a texture composed of so many different tissues as the skin and performing so many important functions, acquires its perfect development but slowly. Connected with the cutaneous system are nails, hairs, and in many of the lower animals horny structures. The glands for the secretion of the sweat open upon the surface of the skin, and the sebaceous glands secreting oily matter

near the mouth of the follicle in which the hair is lodged. Lastly, in some parts of the skin, particularly the tips of the fingers, the lips, and the tip of the tongue, a beautifully delicate apparatus connected with the sense of touch is formed.

63. Mucous membrane.—Closely allied to the skin in structure, and indeed continuous with it, is a sort of internal skin called *mucous membrane*, which lines the digestive apparatus from one end to the other, and also the respiratory organs. The mucous membrane is modified in structure in every part of its course according to the offices it has to discharge. In some situations the surface is hard and even horny, while in others it is soft like velvet. Almost dry and rigid in some places, in others consisting of glands packed closely together and constantly secreting an enormous quantity of fluid. Again, instead of being a secreting surface, a considerable extent is modified to form a highly efficient absorbing apparatus.

Besides the many tissues and organs already enumerated, several very highly elaborate structures are gradually formed which cannot come into use at all until after birth. The development of these continues to advance for some time, and not only is it doubtful if they attain their most perfect condition before the adult period of life is reached, but it is certain that some of them continue to improve for many years afterwards.

64. Organ of smell.— The organ of smell is in its structure much simpler than the other organs of special sense, but the arrangement of the nervous apparatus is very beautiful. The nerves come quite to the surface, and it is probable that odoriferous particles come into actual contact with nerve tissue. The olfactory mucous membrane in very young animals is a tissue in which the ultimate ramifications of nerve

fibres and their relation to other tissue elements may be studied with success.

65. Organ of taste.—The tongue is a highly complex organ; not only is it exceedingly sensitive as an organ of *touch* and *taste*, but the muscles, of which the substance of the tongue is entirely composed, are remarkable for the delicacy and perfection of their movements, and for the wonderfully rapid and varied contractions executed by them, which are purely voluntary. The movements of the tongue so immediately respond to the will that they almost seem to represent the undulations of the mind. By its changes in form, at the same time that a current of air is made to traverse the vocal organ, by the action of other muscles, whose contractions are harmonised with the lingual movements, not only may ideas be expressed in words and rendered evident to others almost as fast as they are formed, but the sounds may be so accentuated as to convey to the understanding of others far more than is indicated by the mere words themselves.

66. Organ of hearing.—The ear is developed at the time of birth, but it continues to improve even for many years afterwards. Its structure is most elaborate, and the arrangement of every part is such that it is not possible to explain its construction by any known laws. To attribute the formation of so complex an organ, consisting of so many elaborate, interdependent, and mutually adapted parts to *evolution* is mere trifling with words. A few years ago it would have been said that its development was due to the gradual differentiation of the originally homogeneous—but such phrases are sad examples of what by worldly-minded persons would be termed imposition. Statements of this kind would certainly justify the inference of clever, if ungenerous critics, that the authorities who employ them must have a supreme contempt for the people whom they profess to be

very anxious to teach, but whom they are really trying to astonish only.

67. Organ of sight.—The eye, the result of a long series of the most marvellous developmental changes, at last appears an organ, the mere structure of the nervous part of which has not even yet been thoroughly elucidated. There is not a portion of the eye that will not excite admiration on the part of the student who investigates it. The adaptation of every structure to the work it will have to perform is most remarkable, and when we consider that this organ, useless without light and formed for light, was produced in utter darkness, it is difficult indeed to understand how anyone can venture to adopt the belief that the various arrangements of tissues are due to the operation of external circumstances, and the properties of the mere matter of the body. From the very first the perfect form the organ was to assume must, as it were, have been determined and foreseen. To say that the fully formed eye existed potentially in the masses of bioplasm, from which its tissues were formed, neither indicates scientific knowledge, nor a love of accuracy, nor candour. The very matter was absent, out of which these tissues were to be formed, and yet their formation was prepared for, and, as it were, anticipated from the very first. All the early and most important changes in the development of an eye cannot be attributed to the operation of any external conditions whatever. They must be due to forces or powers acting from within, and influencing the matter constituting the bioplasm at the time, and these forces and powers exhibit nothing whatever in common with any known forces, properties, or powers of non-living matter.

Mr. Darwin remarks that the telescope "has been perfected by the long-continued efforts of the highest human intellect"; and, he says, we "*naturally infer* (!) that the eye has been formed by a somewhat anala-

gous process." But natural inferences and analogical arguments of this kind do not forward natural knowledge. The perfection of an optical instrument by experiments conducted by man in daylight surely throws marvellously little light upon the question of the formation of an eye in darkness, altogether without man's agency.

We have seen that, as development proceeds, the original mass of simple living matter gives rise, by growth and subdivision, to multitudes of descendants, which succeed one another in regular order until at last a number of bioplasts result, which take part in the formation of tissues differing remarkably from one another in properties, and organs which perform very different kinds of work, duty, or function. But all the different tissues and organs are supplied by vessels and all nourished by the same blood. By the agency of bioplasm, however, very different substances are produced, although the elements of all are derived from the same blood. Thus, *saliva*, *gastric juice*, *bile*, and *urine* have very few properties in common; they are secretions, having very different chemical composition and properties, and perform very different offices. Yet they are all formed from the blood by different kinds of living matter. It is very remarkable that all these bioplasts which have resulted by descent from the same original mass should possess endowments as different from those of the original parents of them all as they are from one another.

No adequate explanation has ever been given of this fact. It will be found upon examination that all the explanations that have been offered only amount to statements of the fact itself in a somewhat roundabout way. Nor can the formation of tissue be adequately accounted for. Form and structure result from the formless and structureless, but to attribute

such phenomena to what has been called "differentiation," is simply degrading science. We are quite ignorant of the exact nature of the changes that occur, but we do know that the bioplasm *lives*, and that the tissue formed by it does not live. We shall see that the distinction between the matter which is actually living and that which is not living is a cardinal fact of very great importance. This indeed appears to me to form the very starting point of physiology. Without recognising the distinction between the living and the non-living, all discussion concerning the phenomena of living beings will only lead to vague and contradictory conclusions, and the use of terms and phrases which perplex the student instead of helping him to learn.

LECTURE IV.

Process of Investigation—Microscopic Characters of Bioplasm—Mode of Growth of Bioplasm of a simple Vegetable Tissue—Sugar Fungus—Bioplasm of Animal Tissue—Extremity of Tuft of Placenta—Bioplasm of Hair—Bioplasm of Amœba—Bioplasm of Mucus—Movement of Bioplasm—Irritability and Contractility—"Molecular Machinery"—Bioplasm constituting new Centres, or Nuclei and Nucleoli—Production of Formed Material—Structure of a Spore of Mildew—Growth—How is the new Matter added?—Importance of the Changes.

68. Process of Investigation.—In order to distinguish the invariably transparent living matter or *bioplasm* from the frequently transparent formed material, it is necessary to pursue a particular method of investigation, which I have fully described elsewhere.* The value of this process depends upon the fact that all *bioplasm is coloured red by an ammoniacal solution of carmine, while all formed material, notwithstanding it has been traversed by the alkaline coloured fluid, remains perfectly colourless.* In practice, certain precautions are necessary, and the density and composition of the colouring fluid must be slightly varied in special cases. But it is necessary that I should state distinctly that, if the process be properly conducted, *every kind of living or germinal matter or bioplasm receives and fixes the colour, while no kind of formed material known is stained under the same circumstances.* I shall have to direct attention

* "How to Work with the Microscope." 4th edition.

to the fact, that the proportion of bioplasm in the same tissue varies at different ages, and that in many different forms of disease the morbid change essentially depends upon a considerable increase in the amount of bioplasm. These facts are most positively demonstrated in specimens prepared according to the method described. Moreover, I shall, by the aid of this mode of investigation, be able to show where the bioplasm ceases and the formed material commences, and in some instances, to distinguish which part of a mass of bioplasm was first and which last formed. The action of the carmine fluid upon the bioplasm is well illustrated by a well-prepared specimen of cartilage of the frog or newt. The cartilage *tissue*, *matrix*, or *formed material* is left perfectly colourless, and although it consists of a firm, and not very permeable material, it has been freely traversed by the carmine fluid. The rapidity with which a comparatively thick layer of the formed material may be traversed by the dark red solution is very remarkable. To illustrate this fact, a few cells may be taken from the liver of a mouse recently killed. The carmine fluid may be allowed just to pass over the cells, and the excess at once washed away with a little weak glycerine. The whole operation can be performed in less than half a minute, and yet the bioplasm of every cell, in this case called the nucleus, will be coloured bright red, while the outer formed part will be left colourless and unchanged. The formed material in this instance consists of a thick layer of soft matter, which, however, has been freely traversed in the course of a few seconds by a fluid which contains glycerine, and is of higher specific gravity than blood-serum.* This enables us to form some idea of

* The fluid which I use in the preparation of my specimens has the following composition:—Ca mine, 10 grains; strong liquor ammonia, ½ drachm; rectified spirit, ½ ounce; Price's glycerine, 2 ounces; distilled water, 2 ounces. The carmine

the great rapidity with which nutrient fluid passes through the tissue or formed material towards the bioplasm or living matter of the cell or elementary part during life. Even the firm and resisting matrix of cartilage is readily permeated by the carmine fluid without being stained in the slightest degree, while the masses of bioplasm are deeply tinged.

69. Colour not due to mere tinting.—The effect produced is very different from the mere tinting which results from soaking tissues or other bodies in coloured fluids. The staining of the bioplasm depends upon altogether different circumstances, and from it we learn highly important facts. Of course every kind of matter may be tinted,—rag, paper, wood, silk, bone, teeth, shell, and almost every formed matter in nature may be coloured bright red by being soaked in certain coloured fluids. As formed material of any kind can thus be dyed, some observers without paying the least attention to the observations which have been made, and without even looking at the specimens and drawings with which my investigations have been illustrated, have hastily inferred that by carelessly steeping tissues in various colouring fluids, all the advantages afforded by the use of an ammoniacal solution of carmine can be gained. I cannot discuss the matter in this place, and shall content myself with directing attention to the evidence adduced. The ridiculous objections that have been advanced even by persons in positions of authority may be replied to by specimens anyone can make for himself with a little trouble, and by the confirmatory researches of observers who have not already committed themselves to doctrines concerning the nature of the phenomena of living beings which are incom-

may be increased to 15 grains if it is desired to stain soft tissues very quickly. In some cases it is necessary to add a little water, and in others more alcohol must be added in order to make the solution permeate the tissue freely.

patible with well-authenticated facts of nature, and calculated only to mislead.

70. Microscopic characters of Bioplasm.—The characters of bioplasm may be studied in the lowest organisms in existence and in plants, as well as in man and the higher animals. Being so very transparent and often embedded in dark and more or less opaque tissue, bioplasm has often been overlooked and has been mistaken for mere passive fluid occupying a *space* or *vacuole* in the tissue. We shall have many opportunities of studying it, but it may be well to repeat that bioplasm or living matter is, as far as can be ascertained by examination with the highest powers, perfectly structureless. It exhibits the same characters at every period of existence, and in every living organism.

71. Bioplasm of sugar fungus.—The bioplasm of the thallus of the growing sugar fungus exists in considerable quantity, and is well adapted for examination. It may be found in abundance in mouldy jam, and it may be stained without much difficulty. The growing extremity of the branch is rounded, and here the process of growth is going on with great activity; new living pabulum is being converted into living bioplasm with great rapidity. When the operation of staining has been conducted successfully, these growing extremities will be found to be much more deeply stained than the rest of the bioplasm.

72. Bioplasm of tuft of placenta.—A corresponding fact may be demonstrated if one of the little tufts of the placenta (a temporary organ of the embryo by which the nutrient matter is separated from the maternal blood, and which also effects the necessary changes as regards oxygen and carbonic acid) is submitted to examination. At the extreme end of each tuft is a collection of bioplasts which is intensely stained by the carmine fluid. Behind this, and growing towards it, is the vascular loop; but as the

tufts grow, the mass of formless, structureless bioplasm at the end of each moves onwards, the vessels being developed in its rear. This formless living matter moves forwards, burrowing, as it were, into the nutrient pabulum, some of which it takes up as it moves on. It is not *pushed* from behind, but it moves forwards of its own accord. In a similar manner the advancing fungus bores its way into the material upon which it feeds, and the root filament insinuates itself into interstices between the particles of the soil, where it finds the pabulum for its nutrition.

73. Bioplasm of the hair.—In the hair the bioplasm grows and multiplies at the base or bulb, pushing the firm and already formed tissue before it. The bioplasm of the root of a plant increases at the extremity of a filament which it spins off, as it were, behind it; in the case of the hair, on the other hand, the tissue already formed is *pushed on* by the production of new texture in its rear. The extremity of the hair is its oldest part, and nearest to its root is the tissue which was most recently formed from pabulum absorbed from the blood.

74. Vital power.—But whether bioplasm moves on in its entirety, or, advancing from a fixed point, forms a filament, a tube, or other structure which accumulates behind it, or remains stationary itself, while the products of formation are forced onwards in one direction, or outwards in all, the nature of the force exerted is the same, and due to the *marvellous power which one part of a living mass possesses of moving in advance of other portions of the same, as may be actually seen to occur in the humble amœba, in the mucus or in the white blood-corpuscle from man's organism, as well as in the pus-corpuscle formed in disease.*

75. Amœba.—Among the simplest living things known to us are the amœbæ, which might be almost described as animate masses of perfectly transparent

moving matter. Amœbæ can be obtained for examination by placing a small fragment of animal or vegetable matter in a little water in a wine-glass, and leaving it in the light part of a warm room for a few days. I have found it convenient to introduce a few filaments of cotton wool into the water. The amœbæ collect amongst the fibres, which prevent them from being crushed by the pressure of the thin glass cover. The delicate material of which these simple creatures are composed exhibits no indications of actual structure, although it is darker and more granular in some parts than in others.

76. Bioplasm in different organs and tissues.—The bioplasm of all organisms, and of the tissues and organs of each organism, exhibits precisely the same characters. It *lives*, and *grows*, and *forms* in the same way, although the conditions under which the phenomena of life, growth, and formation are carried on differ very much in respect of different kinds of living matter. A temperature at which one kind will live and grow actively will be fatal to many other kinds. So, too, as regards pabulum—substances which are appropriated by one form of bioplasm will act as a poison to another. But the way in which the bioplasm moves, divides and subdivides, grows, and undergoes conversion into tissue, is the same in all. Many remarkable differences in the structure, properties, action, and character of the things that are formed are associated with close similarity, if not actual identity, of composition of the matter that forms them. These differences cannot, therefore, be attributed to the properties of the elements, to physical forces, chemical affinities, or to characters which we can ascertain or estimate by physical examination, but they must be referred to a difference in *power* which is inherited from pre-existing bioplasm, which we cannot isolate, but which it would be quite unreasonable to ignore.

77. Movements of bioplasm.—One characteristic of every kind of living matter is spontaneous movement. This, unlike the movement of any kind of non-living matter yet discovered, occurs in all directions, and seems to depend upon changes in the matter itself, rather than upon impulses communicated to the particles from without. I have been able to watch the movements of small amœbæ, which multiplied freely without first reaching the size of the ordinary individuals. I have represented the appearance under a magnifying power of 5,000 diameters of some of the most minute amœbæ I have been able to discover. Several of these were less than $\frac{1}{100000}$th of an inch in diameter, and yet were in a state of most active movement. The alteration in form was very rapid, and the different tints in the different parts of the moving mass, resulting from alterations in thickness, were most distinctly observed. In these movements one part seemed, as it were, to pass through other parts, while the whole mass moved now in one, now in another direction, and movements in different parts of the mass occurred in directions different from that in which the whole was moving. What movements in lifeless matter can be compared with these?

78. Changes ending in formation of a capsule.—The movements above described continue as long as the external conditions remain favourable; but, if these alter and the amœba be exposed to the influence of unfavourable circumstances—as altered pabulum, cold, &c.—the movements become very slow, and at last cease altogether. The organism becomes spherical, and the trace of soft formed material upon the surface increases until a firm protective covering, envelope, or cell-wall, results. In this way, the life of the bioplasm is preserved until the return of favourable conditions, when the living matter emerges from its prison, grows, and soon gives rise to a colony of

new amœbæ, which exhibit the characteristic movements.

79. Mucus Corpuscle.—Every one knows that upon the surface of the mucous membrane of the air-passages, even in health, there is a small quantity of a soft viscid matter generally termed *mucus*. This mucus, said to be *secreted* by the mucous membrane, contains certain oval or spherical bodies or corpuscles, which are transparent and granular. From the changes of form which take place in them, it is certain that the matter of which they are composed is almost diffluent. These corpuscles are *mucus corpuscles*, but they have no cell-wall. They are separated from each other by, and are embedded in, a more or less transparent, viscid, tenacious substance formed by the corpuscles themselves, and termed *mucus*.

80. Its vital movements.—No language could convey a correct idea of the changes which may be seen to take place in the form of a living mucus or pus corpuscle or white blood-corpuscle; every part of the substance of the body exhibits distinct alterations within a few seconds. The material which was in one part may move to another part. Not only does the position of the component particles alter with respect to one another, but it never remains the same. There is no mere *alternation* of movements as in muscular contraction. Were it possible to take hundreds of photographs at the briefest intervals, no two would be exactly alike, nor would they exhibit different gradations of the same change; nor is it possible to represent the movements with any degree of accuracy by drawings, because the outline is changing in many parts at the same moment. I have seen an entire corpuscle move onwards in one definite direction for a distance equal to its own length or more. Protrusions would occur principally at one end, and the general mass would gradually follow. Again, protrusions would take place in the same direction, and

slowly the remainder of the corpuscle would be drawn onwards, until the whole had moved from the place it originally occupied, and advanced onwards for a short distance in the mucus in which it was embedded. From the first protrusions smaller protrusions very often occur, and these gradually become pear-shaped, remaining attached by a narrow stem, and in a few seconds perhaps again become absorbed into the general mass. From time to time, however, some of the small spherical portions are detached from the parent mass, and become independent masses of bioplasm, which grow until they become ordinary "mucus corpuscles." Are these phenomena, I would ask, at all like any known to occur in lifeless material?

81. Of the molecules.—The component molecules evidently alter their positions in a most remarkable manner. One molecule may move in advance of another, or round another. A portion may move into another portion. A bulging may occur at one point of the circumference, or at ten or twenty different points at the same moment. The moving power evidently resides in every particle of the very transparent, invariably colourless, and apparently structureless matter. By the very highest powers only an indication as if of minute spherical particles can be discerned. Because "molecules" have been seen in some of the masses of moving matter, the motion has been attributed to these visible particles. It is true the molecules do move, but the living transparent material in which they are situated can be seen to move away from the general mass, and into this extended portion the molecules or granules then pass. The perfectly transparent matter *moves first*, and the molecules flow into it or are moved with it. The movements cannot, therefore, be ordinary *molecular movements*. It has been said that the movements may result from diffusion, but what diffusion

or other movements with which we are acquainted at all resembles these? Observers have ascribed the motion to a difference in density of different parts of the mass, but who has been able to produce such movements by preparing fluids of different density? But further, in the case of bioplasm or living matter, these supposed fluids of different density in some unexplained way make themselves and in some undiscovered manner retain their differences in density!

82. Irritability—Contractility.—Nor is it any explanation of the movements to attribute them to inherent "irritability," unless we can show in what this *irritability* essentially consists. Some authorities dismiss the matter by saying that the movements depend upon the property of "contractility," but the movements of bioplasm are totally distinct from "contractility," such as is manifested by muscular tissue. These remarkable movements take place in every direction, and every movement differs from the rest, while in muscular contraction there is a constant repetition of changes occurring alternately in directions at right angles to one another. Hence, if the movements in question be due to contractility, it is necessary to admit two very different kinds of contractile property, which are not of the same nature and not due to like circumstances.*

83. Movements in the bioplasm of plants.—The movements in the mucus corpuscle and in the *amœba*, are of the same nature as those which occur in the bioplasm of many plants, as is easily observed in the cells of the leaves of the vallisneria or the anacharis, in the chara, and in the hairs of the flower of Tradescantia; and the appearance of the living matter under very high powers is precisely the same in all cases.

84. Movements in morbid bioplasm.—Similar

* See my paper "On Contractility as distinguished from purely vital movements."—"Trans. Mic. Soc.," 1866.

movements certainly occur, in the white blood corpuscle and in the lymph corpuscle, as well as in pus, and in cancer, and in every kind of living matter in health and in disease, though the movement is not in all cases sufficiently active to be easily detected. In some instances the movements continue for many hours after the living matter has been removed from the surface upon which it grew. In other cases, and we shall not be surprised that this should be so in the higher animals, death occurs the instant the conditions under which the living matter exists are but slightly modified. In many instances no movements can be seen, but the evidence of their occurrence is almost as decided as if they were visible, for we demonstrate certain results which cannot be explained unless such movements as those referred to have taken place.

I have often tried to persuade the physicist, who has so long prophesied the existence of molecular machinery in living beings, to seek for it in the "colourless, structureless," bioplasm. But he contents himself with asserting that such machinery exists, although he cannot see it or make it evident to himself or others.

83. Bioplasm constituting new centres.—Nuclei and nucleoli.—In many masses of bioplasm a smaller spherical portion, often appearing to be a mere point, is observed. As already mentioned in 36 §, this is known as the nucleus. In some cases this divides before the division of the parent mass takes place. The division of the nucleus is not, however, necessary to the division of the surrounding bioplasm, as was formerly supposed, for division takes place in cases in which no nuclei exist. Moreover it frequently happens that one or more of these smaller spots or spherical masses (nuclei) may appear in the substance of the bioplasm, *after* a portion has been detached from the parent mass. These are *new centres* composed

of living bioplasm. Within them a second series (nucleoli) is sometimes produced. Marvellous powers have been attributed to nuclei and nucleoli, and by many they are supposed to be the agents alone concerned in the processes of multiplication and reproduction. These bodies are always more intensely coloured by alkaline colouring matters than the other parts of the living matter or bioplasm, a fact which is alone sufficient to show the difference between a true *nucleus* or *new centre*, and an oil globule, which has often been wrongly termed a nucleus or a nucleolus. In certain cases it would appear that as the process of formation of new centres, one within the other, proceeds, new powers are acquired, or, if we suppose that all possessed the same powers, those masses only which were last produced retain them, and manifest them when placed under favourable conditions.

86. Nuclei and nucleoli do not produce formed material.—Although nuclei and nucleoli are bioplasm, they do not undergo conversion into formed material. Under certain conditions the nucleus may increase, and exhibit all the phenomena of ordinary bioplasm—new nuclei may be developed within it, new nucleoli within them; so that ordinary bioplasm may become formed material, while its "nucleus" grows larger and becomes ordinary bioplasm. The original nucleolus then becomes the nucleus, and new nucleoli originate and make their appearance in what was the original nucleolus. The whole process consists of evolution from centres, and the production of new centres within pre-existing centres. Zones of colour, of different intensity, are often observed in a young elementary part coloured by carmine; the outermost or oldest, or that part which is losing its vital power, and becoming converted into formed material, being very slightly coloured,—the most central part, or the nucleus, *although furthest from the colouring solution*, exhibiting the greatest intensity of colour.

87. Bioplasm destitute of nuclei.—Bioplasm in a comparatively quiescent state is not unfrequently entirely destitute of nuclei, but these bodies sometimes make their appearance if the mass be more freely supplied with nutrient matter. This fact may be noticed in the case of the connective tissue corpuscles, and the masses of bioplasm connected with the walls of vessels, nerves, muscular tissue, epithelium, &c., which often exhibit no nuclei (or according to some, nucleoli); but soon after these tissues have been supplied with an increased quantity of pabulum, as I have shown is the case in all fevers and inflammations, several small nuclei make their appearance in different parts of the bioplasm.

88. Mode of origin of nuclei.—So far from nuclei being formed *first* and the other elements of the elementary part afterwards, *deposited around them*, as used to be taught, they make their appearance in the substance of a pre-existing mass of bioplasm, as has been already stated. The true nucleus and nucleolus are not composed of special constituents differing from the bioplasm in chemical composition, nor do they perform any special operations. Small oil-globules, which invariably result from post-mortem change in any form of bioplasm matter, have often been mistaken for nuclei and nucleoli, but these terms if employed at all should be restricted to the new centres of living matter referred to.

89. Production of formed material from bioplasm.—We have now to consider the manner in which the formed material is produced from the clear, transparent structureless bioplasm,—and this is a most interesting inquiry, involving questions of fundamental importance. It has been shown that the amœba may become surrounded by a capsule (§ 78), and the outer part of a mucus corpuscle become firmer than bioplasm, so as to form a "cell wall" to the oval mass of living matter. This alteration is probably de-

pendent in great measure upon change in the external conditions. When these are favourable, the bioplasm of the amœba and the mucus corpuscle grows very fast and multiplies rapidly, but when the external conditions are unfavourable, and the supply of pabulum very limited, the bioplasm ceases to increase rapidly, and becomes changed upon the surface; a firm material being produced which protects the living matter within from destruction, but which renders its free movement impossible. Under such circumstances, the so-called mucus corpuscle may assume the characters of an epithelial cell.

But the growth of bioplasm and the production of the *formed material* can be so well studied in the lower fungi, that I shall venture to draw attention to the phenomena as they occur in a specimen of this lowly organism before alluding to the change as it occurs in man and animals.

90. Structure of a spore of mildew.—If one of the simplest structures—the microscopic sporule, which is so light that it may be wafted long distances by currents of air—be examined, we shall find that it is not the same in every part. It consists externally of a delicate transparent, glass-like texture, and within of a material having a very faintly granular appearance. In order to demonstrate this fact, a little ordinary mildew dust, which is one of the lowest forms of existence, may be examined. The little round bodies which compose it are comparatively large, and well suited for investigation. They may be studied in glycerine under a twelfth of an inch object glass. Each of these corresponds to a single *cell* or *elementary part* of the more complex tissues. It has a tolerably thick well-defined outline, while the interior is perfectly transparent. When this transparent matter is expressed and placed under very high magnifying powers, numerous very minute particles like dots will be observed. Here then are two kinds of ma-

terial, the one situated externally, firm, glass like, and arranged so as to form an investing membrane closed at all points; the other lying within, soft, and exhibiting no form or structure whatever.

91. Change in the spore.—If one of these spores falls upon a moist surface where the conditions favourable for its development are present, it soon undergoes remarkable changes, and abundant growth occurs, so that by the germination of this one minute particle many hundred times its weight of material may result in a very short time, and every portion of the newly formed bioplasm is itself capable of further growth. The changes which occur are of exceeding interest and worthy of the most attentive study. The facts which we shall learn cannot fail to influence our general conclusions concerning the nature of the process of growth as it occurs in all living things in health and disease, while at the same time they serve to impress upon us forcibly the amazing difference between *growth*, as it occurs even in this simple organism, and the *mere increase* in size which the crystal undergoes, and which has been very wrongly termed growth.

92. Growth of the bioplasm.—Next a new change is observed at one point in the membrane. A small orifice is seen, through which a little of the granular contents of the capsule, covered by a thin layer of the inner part of the membrane, makes its way, and thus a small pear-shaped nodule is formed which projects through the external membrane. This then grows very quickly, and soon forms a sort of process or outgrowth, still connected with the original mass of bioplasm by a very thin pedicle. Growth continues with considerable rapidity, and soon a new oval spore like the original one results. These facts may be demonstrated in the rapid multiplication of the yeast-cells in ordinary fermentation. The point of attachment becomes less and less, until at last it is completely

separated, and the bud or offset becomes a free and independent particle, exactly resembling that from which it sprung (except that it is smaller), and capable of growing and giving rise to new individuals like itself, by a repetition of the process by which it was formed.

93. Another kind of growth.—The above is one way in which the particles may multiply, but there are others. In one of these, too, an orifice forms in the membrane of the particle of mildew, and a little of the soft transparent material escapes, but it does not separate as in the first instance; it remains in connexion with the mass, and grows out into a narrow thread-like process. A long undulating stem gradually results, from various parts of which new buds proceed which grow, and branch like the original one, and sometimes with astonishing rapidity. At first the membrane or formed material of these branches is extremely thin, but it gradually becomes thickened by the deposition of new formed material within, until it acquires considerable firmness, and at the same time it increases in breadth. If the conditions cease to be favourable to growth, the branches cease to extend, and the membranous protective covering acquires increased thickness. Within the sheath is found the transparent matter, from which a number of little spherical bodies or very minute growing particles like those observed within the spherical spore may be obtained.

94. Increase of bioplasm and production of formed material.—These two processes—the extension of bioplasm and the production of formed material—occur under different and often opposite conditions; the circumstances favourable to the rapid increase of bioplasm being unfavourable to the production of formed material, and *vice versâ*, so that an abundant supply of pabulum is associated with rapid growth of the bioplasm, a scanty supply with the production of formed material. The former is a very rapid process,

the latter a slow one. In a few hours bioplasm may multiply itself a hundredfold, but days or weeks may be required for the formed material to double in amount. If, after rapid growth from exposure to favourable conditions, the bioplasm be brought under the influence of adverse circumstances, the formed material gradually increases in thickness. At the same time the amount of bioplasm becomes less and less, for it undergoes conversion into the formed material. The latter, therefore, becomes thickened by deposition, *layer within layer*. At last a mere speck of bioplasm may remain, surrounded by a very thick investing membrane, which acts as a most efficient protection to the trace of bioplasm that remains. This being protected resists the influence of extreme cold and retains its vitality until external conditions become again favourable, when the trace of living bioplasm soon increases, pushes through spaces or orifices in the thickened membrane, much of which it even consumes as pabulum, and the rapid growth already referred to is resumed.

95. Death of the mildew.—If such a living thing be placed under certain unfavourable conditions, its vital properties will be destroyed. The transparent living matter in its interior will shrivel up and die, but this will be attended by no obvious alteration in the external membrane. The part which exhibits form (formed matter) remains; that which is without form (*living matter*) is alone killed or destroyed.

96. How is the new matter added produced?—In the thickening of the outer formed matter then, how is the new material produced? Is the thickening occasioned by deposit upon the outer surface of the investing membrane, or is the new matter produced by the soft, formless matter in the interior? To put the question still more simply, is the transparent capsule, the so-called *cell-wall*, formed by deposition of matter from the fluid surrounding it, as in the increase of a

crystal, or is it formed from within? Which is the oldest part of the capsule, its external or internal surface? If the new matter were deposited upon the outside, we should expect to find that the membrane would become thicker and thicker as the growth of the organism advanced, while the central portion would remain unaltered. This, however, is not the case. On the contrary, we find that as growth proceeds, the wall in most cases becomes considerably thinned. It is clear, therefore, that any increase in size cannot be due to deposition from without. The matter deposited upon the *inner* surface of the capsule is always softer than its general substance, and the external surface of old capsules is cracked and ragged. This ragged portion is oldest. In many of the algæ (sea-weeds) this external surface serves as a nidus for the development and growth of smaller algæ—a fact which clearly shows it has ceased to be active, is undergoing disintegration, and becoming fitted for the pabulum of other things, and no longer capable of resisting the action of external conditions. This, the oldest part of the capsule, is now undergoing decay, and the small algæ are living in part upon the products thus produced. The new material is invariably added upon the inner surface of the capsule, layer within layer. Of the several layers the innermost is the youngest, and the outermost the oldest portion of the structure. From this it follows that the inanimate material for the nourishment of these living things must pass through the outer membrane, and be taken up by the living matter within, which communicates to it the same properties and powers which this living matter itself possesses, and which it has inherited from pre-existing particles. At present we cannot get further than this. I am ignorant of the cause of the changes which occur, but the facts as I have stated them are true.

97. Importance of these changes in bioplasm.—

This rapid increase of bioplasm under favourable conditions is a fact of the greatest interest and importance in reference to certain changes occurring in disease of the higher tissues of plants, animals, and man. For we shall find that just as the bioplasm of the fungus may grow and live and give rise to new bioplasm at the expense of the formed material already produced, so the bioplasm of an elementary part of the highest organism may increase and consume its formed material. In this way we shall see that firm and scarcely changing tissue may become the seat of active change, and ultimately be removed. Thus is the fatty matter of adipose tissue removed, and the hard, compact tissue of bone scooped out to make room for new osseous texture. In this way the abscess and the ulcer commence, and the "softening" of cartilage and other hard textures is brought about. The pathological process known as "inflammation" is due to the increase of bioplasm. In certain forms of cancer the process is seen in its most active, and to us, most painful form; for as the growth proceeds, not only is the formed material of adjacent textures rapidly consumed, but no sooner has the soft cancer-tissue been produced, than it is consumed in its turn by new cancer-tissue, and this by more, until an enormous mass of soft, evanescent, spongy texture results, which destroys the poor patient by its enormous exactions upon his terribly exhausted system.

MICROSCOPICAL PREPARATIONS ILLUSTRATING LECTURE IV.

	No. of diameters magnified.
12. Bioplasm in act of division, certilage, newt	215
13. Bioplasm from mucus from the throat	215
14. Spores, &c., sugar fungus	700
15. Growing spores, penicillium	700
16. Growing branches and fructification, spores, penicillium	215
17. Budding and branching of sugar fungus	215
18. Masses of bioplasm at the extremity of radicle of growing potato	130

LECTURE V.

Of Elementary Organs and Tissues—Of the Functions of Organs and Tissues—Changes during Life—Of the Elementary Units—Erroneous views on Cell-Formation—Formation of the Unit or Cell—Formed Matter—Things essential to the Cell—Nutrition of an Elementary Part—Of the increase of Cells—Cuticle—Hair, Horn, Nail—Epithelial Textures hardened with Calcareous Matter—Enamel—Dentine—Dentinal "tubes"—Of Secreting Cells—Different Products formed by the same Bioplasm—Fat-Cell—Starch-Cell—Secondary Deposits—Ciliated Cells—Pigment Cells—Salivary Corpuscles.

98. Elementary organs and tissues.—The body of the adult man or animal is made up of many different organs, which perform very different offices. These all derive the elements of their nutrition from the blood, and are all under the control of the nervous system. The nervous system consists of many different parts, but these are all connected by inter-communicating cords or nerve fibres. Each organ is composed of a great number of elementary organs closely resembling one another, and so combined that the work of all is united together. Every *elementary organ* is made up of a variety of textures differing from each other in appearance and structure, and in the offices they discharge.

99. Tissues of a limb.—If a transverse section be made, for example, of the fore leg of an animal, we find externally a texture which is well known to all as the skin—a tissue not simple in its structure, but

made up of several parts, each performing an important *office* or *function*. Beneath this, proceeding from without inwards another tissue comes into view, very different from the first, called *fat*, or as it is termed more correctly, *adipose tissue*. Beneath this, again, is a firm, unyielding, glistening material, spread out like a membrane, admirably adapted for the protection of the more delicate structures beneath. This is composed of a form of *white fibrous tissue*, which is called *Fascia*. Next to this we come to a peculiar tissue, which alternately becomes shortened and lengthened according as it is influenced by nerves. The change is said to depend upon the property of contractility. Ordinarily, the tissue in question is spoken of as *flesh*, but we call it *muscle*. In connection with this, we invariably notice certain cords which are the *nerves*. Their office is to bring the muscular substance into relation with the brain and other parts of the nervous system, and to convey to it from the nerve centre those various impulses by which not only its contraction and relaxation is effected, but by which the exact degree of contraction willed is established. Besides the tissue described, we observe in various parts of the limb certain tubes, which are of two kinds—the one, with thick, tough, and very elastic walls; and the other, with walls less elastic, thinner, and flaccid. Both sets of tubes are in connection with the heart, but the one set (*arteries*) performs the office of conveying the blood from the heart to the tissues; the other (*veins*), that of returning the blood from the tissues to the heart, §§ 40, 46. Besides these, there are some very delicate tubes which are called *lymphatics*, which transmit a colourless fluid from the tissues to the venous circulation. Lymphatics cannot be seen without being filled with some coloured substance. Lastly, we notice the bone, a firm, hard, solid tissue, in the interior of which is a cavity containing that peculiar

modification of adipose tissue known as *medulla* or *marrow*.

100. Of the functions of Organs and Tissues.—The functions or offices discharged by organs and tissues have been divided into two great classes, the *animal*, and the *organic* or *vegetative functions*. The one class is characteristic of the higher animals only, but the other is common to all living things. This division, however, is not strictly accurate, for, in man and the higher animals, the so-called vegetative functions could not be performed, if the so-called organs of animal life did not act properly. The animal and organic functions of the higher animals are mutually dependent, and cannot strictly be regarded as belonging to separate systems. The so-called animal functions comprise, *Locomotion*, *Innervation*, and *Special Sense*. The vegetative functions so widely distributed, comprise *Digestion*, *Absorption*, *Circulation*, *Respiration*, *Secretion*, *Generation*, and *Development*, and the *development of Heat*, *Light*, *and Electricity*. In the lowest organisms, some of the most important vegetative functions are performed through the instrumentality of the general surface; while in man and the higher animals a separate organ is set apart for the performance of each function. If I was considering these different functions, I should commence with the functions of organic life in the order in which I have enumerated them, for this seems the most natural mode of arrangement. First of all, the food is introduced into the organism, and after being altered by certain preliminary processes, is subjected to *Digestion*, by which it is rendered soluble, and fitted for the next process, that of *Absorption*. By this the nutritive material is taken up and introduced into the blood, and ultimately becomes converted into blood. Thus we come to the consideration of the function of *Circulation;* and as we follow the blood

in its course through the body, our attention will naturally be drawn to the examination of those remaining processes—viz., *Respiration* and *Secretion*, by which great and most important changes are brought about in the condition of the circulating fluid, various substances being separated from it for ulterior uses, or for complete removal from the body. Lastly, comes *Generation*, the process by which the multiplication of individuals is effected.

101. Incessant change in everything living.—Living organisms, as well as every particle of living matter. are incessantly undergoing change in every part, but the rate of change varies marvellously in different cases. Some materials, passing through the stages of living or *forming* matter, *formed* matter and products of disintegration, in a few minutes, while others last for many years as *formed* structure, and perform an important office during the whole time. New parts are constantly being formed, which grow, arrive at maturity, pass through certain stages of existence, and then, having performed their office, die, are cast away, and succeeded by others.

102. Of the minute elementary parts of an Organ or Tissue.—The changes in question affect every one of the microscopic anatomical elements of which every tissue and every organ is composed. The anatomical unit, which performs the unit of work, seldom measures more than the one-thousandth of an inch in diameter, and, in some cases, the part possessing structure and performing function, is far less than this.

In order, therefore, to form any correct idea of the changes which go on in every part of the body of a complex living being, it is necessary to study carefully the structure and the changes of one of these numerous elementary units, of which every tissue and organ may be regarded as a collection. Since the time of Schwann and Schleiden, who wrote in

1838, every writer on minute anatomy and physiology has described at some length the structure of the "cell." This "cell" has been regarded as the anatomical unit, and it has been often stated that all the different tissues consist of "cells." The "cell" is a complex body, and different properties have been supposed to be manifested by the several parts of which a perfect cell is composed. In order that certain bodies which could not be included under the ordinary definition of the cell might be comprised in the cell category, the anatomical unit it was supposed might be modified in certain special particulars and in exceptional cases. A body in connection with which no cell wall could be detected was supposed to have a cell wall in a fluid state, of the consistence of the soap-bubble: or it was contended that it might have had a cell wall at an earlier period of its life; or the cell without wall was called a free nucleus, which it was inferred had escaped from its capsule. Many other ingenious devices have been adopted to evade the difficulty, which has been felt by every one who has examined tissues, of bringing each anatomical unit at all periods of its life into the cell category. But, after all, the simple fact is this, that no "cell" exhibits cell wall, cell contents, and nucleus at every period of its existence, while some cells do not possess any structure to which either of these terms can be properly applied at any period. There are, then, "cells," consisting of cell wall only, and "cells" consisting of a "nucleus" only, and yet the original definition of cell has been repeated in almost all our text-books even up to this very time.

As regards the *formation* of "cells," we have the most contradictory statements. Some tissues are admitted not to be composed of cells at all, by authorities who nevertheless cling to the cell theory. So far from the "cell" being the essential and the

earliest form of every structure, the "cell," as defined, never exists at an early period of development, and although it may be convenient to retain the name "cell," as representing generally the anatomical unit, we must not in any case expect to find the complex body, which it has been stated over and over again is actually present.

103. Erroneous views concerning "Cells."—All that can be detected at an early period is a little mass of bioplasm as already stated, § 11, 45. In some cases, new centres are to be seen in the substance of this, but the mass may be destitute of these. As regards the so-called cell wall, this is always absent at an early period of development. Moreover, when *cell wall* or *intercellular substance*, as it has been wrongly termed, is to be seen, the process of division and subdivision, and all the active phenomena, occur in the bioplasm only, and the cell wall and intercellular substance take no part in the process.

Dr. Carpenter in this country, Dr. Tyson in America, Dr. A. Nicholson and other observers, have accepted to some extent the views advocated by me since 1860, but the majority of writers continue to teach the old doctrines, taking care, however, to modify certain of the details, and to alter the meaning of many of the terms employed. In many instances, it is to be feared that such attempts serve only to perplex the student more and more. Mr. Huxley continues to teach that, "There is a time when the human body, or rather its rudiment, is of one *structure* throughout, consisting of a more or less transparent *matrix*, through which are scattered minute rounded particles of a different optical aspect. These particles are called *nuclei;* and as the matrix or matter in which these nuclei are embedded, readily breaks up into spheroidal masses, one for each nucleus, and these investing masses easily take on the form of

vesicles or cells; this primitive structure is called cellular, and each cell is said to be nucleated."

Now it would not be easy to find a paragraph in a work having any pretensions to accuracy which conveyed more incorrect information in the same number of words. Actual observation proves that there is a time when the body has *no structure whatever*, when there is *no matrix*, when there are *no* particles of a different optical aspect, when there are no nuclei. The matrix *never* "breaks up" into spheroidal masses, though it may *be broken* up. The material round the nucleus is *not* applied to it as an investing mass, for the latter exists before the former, and the nucleus arises in the so-called investing mass. Mr. Huxley has been very severe on text-books, but I doubt if he could point out anything in the way of description more thoroughly at variance with facts than his own description of tissue formation which I have quoted. He is surely laughing at us when he tells us that cell wall and intercellular substance become "*variously modified*," both chemically and structurally, and "*give rise*" to the peculiarities of the different completely formed tissues! Is this an ingenious device for trying to make the reader fancy that some highly complex phenomenon is being philosophically explained to him by some novel method of circumlocution? The student will however find that the only information he gains concerning the formation of tissue is, that cell wall and intercellular substance become "variously modified!"

104. Investigation of the nature of the elementary part.—If the student desires to investigate the changes which occur during the formation of tissue, he will find it desirable to discard entirely all the complex phraseology and arbitrary definitions which have so long retarded, and still retard, progress in this department of knowledge. He will find the phenomena far more easy to understand than he would

have been led to anticipate after studying the statements in elementary treatises. Instead of cells with cell walls, cell contents, and nuclei he will find what I have already adverted to, simply two kinds of matter—one *forming*, the other *formed.*

In 1859, I drew attention to the significance of germinal matter or bioplasm, and showed that this constituted the organism of the amœba and bodies of this kind, that the white blood corpuscle, the pus corpuscle, and all the so-called naked nuclei, were composed of it, and that it was to be detected in every tissue at every period of life. By changes in the germinal or living matter, the cell wall, intercellular substance, and every kind of tissue, everything peculiar to living beings, results. I described how, in all structures, no matter how they differed from one another, the germinal or living matter could be distinguished with certainty from the formed material, and showed that the living moving matter in the vegetable cell, the matter of the amœba, and that of the white blood corpuscle, was represented in every cell or elementary part of every tissue of man and animals, in health and also in disease.

105. The anatomical unit or elementary part or Cell.—The living matter, with the formed matter upon its surface, whatever may be the structure, properties, composition, and consistence of the latter, is *the anatomical unit, the elementary part, or cell.* This may form the entire organism, in which case, it must be regarded as a complete individual. Millions of such elementary units or cells are combined to form every tissue and organ of each individual man or animal. However much organisms and tissues in their fully formed state may vary as regards the character, properties, and composition of the formed material, all were first in the condition of *clear, transparent, structureless, formless* living matter. Such matter exists in every *growing* cell, and every cell *capable of growth*, contains

it. The young cell seems to consist almost entirely of this living material—a fact well observed in a specimen of cuticle from the young frog, which may be contrasted with more advanced cuticle from the same animal. In the mature cells of the fully formed cuticle only a small mass of bioplasm (usually termed the nucleus) remains.

106. Varying proportion of bioplasm in the "Cell." —In the fully formed fat cell there is so little bioplasm left that it may easily be overlooked. In disease, on the other hand, the bioplasm may increase to three or four times its ordinary amount, when it becomes a very striking object. The ovum at an early period of its development is but a naked mass of bioplasm, without a cell wall, but having a new centre and often numerous centres (known as germinal spots or nuclei) embedded in it around these, a capsule or cell wall is ultimately formed.

107. Formation of the "Cell."—The mode of formation of the cell, or elemental unit, as well as the origin from it of other units, is well illustrated in the formation of the ovum. The cells constituting the tissue of the ovary of the common stickleback are very easily demonstrated, and amongst them are seen true ova at a very early period of development. The youngest of these ova differs but little from the "cells" amongst which it lies. It is, in fact, but one of these which has advanced in development beyond the rest. Small but complete ova may be seen with their bioplasm, or living matter, here called germinal vesicle, surrounded by the yolk which consists of formed matter. In the germinal matter are seen numerous germinal spots, which are new living centres of growth originating in living matter. In these are new centres, and in these last, others would have appeared at a later period. The growth of an elemental unit always takes place from within, so that the surface is always the oldest portion. The

matter of which the cell wall or capsule is composed was bioplasm long before any cell wall was to be discovered. On the formation of a cell of epithelium see § 117.

108. Of formed material and tissue.—The material called tissue, exhibiting a definite structure, is not simply deposited, like a crystal, from a solution of the same substance, as has been suggested by some authorities, nor does it result from the "*fibrillation*," "*vacuolation*," or "*stratification*" of a previously homogeneous fluid or viscid mass, or by the aggregation and coalescence of little particles precipitated from an albuminous fluid, but it is invariably formed from living matter, as this ceases to manifest its vital properties. Every particle of matter that is to become tissue must first pass through the *living state*, and the properties, characters, and composition of the *tissue* will be determined partly by the *internal forces or powers* of the living matter acting upon the elements of which it is composed, and partly by the *external conditions* present at the time when these pass from the living to the formed state.

109. Varying characters of formed matter.—The formed material or matter resulting from the death of bioplasm or living matter under certain conditions varies remarkably. It may be a fluid holding certain peculiar substances in solution, like bile, a viscid matter like mucus, a perfectly transparent structureless membrane, or a material exhibiting a definite structure. To the latter the term *tissue* is usually applied. Tissue may consist of a scarcely visible web of very delicate fibres, holding in its meshes a perfectly transparent fluid containing but a trace of solid matter. It may exhibit well-defined characters, like cartilage, bone, etc., or it may manifest peculiar and very remarkable properties like muscle and nerve.

110. Matter essential to the elemental unit or cell.

—All that is essential in the cell or elementary part is *matter that is in the living* state, germinal matter, and matter that *was* in the living state, formed material. With these is usually associated a certain proportion of matter about to become living, the pabulum or food. So that we may say that in every living thing we have matter in three different states:—

Matter about to become living;
Matter actually living; and
Matter that has lived.

The last, like the first, is non-living, but, unlike this, it has been in the living state, and has had impressed upon it certain characters which it could not have acquired in any other way. By these characters we know that it lived, for we can no more cause matter artificially to exhibit the characters of the dried leaf, the lifeless wood, shell, bone, hair, or other tissue, than we can make living matter itself, in our laboratories.

111. Cells not like bricks in a wall.—Cells forming a tissue have been compared to bricks in a wall, but the cells are not like bricks, having the same constitution in every part, nor are they made first and then embedded in the mortar. Each brick of the natural wall grows of itself, places itself in position, forms and embeds itself in the mortar of its own making. The whole wall grows in every part, and, while growing, may throw out bastions which grow and adapt themselves perfectly to the altering structure. Even now it is argued by some that, because things, like fully formed cells, may be made artificially, the actual cells are formed in the same sort of way—an argument as cogent as would be that of a person who, after a visit to Madame Tussaud's exhibition, seriously maintained that the textures of our bodies were constructed upon the same principles as the life-like wax figures.

112. Cells contain no molecular machinery.—Every

one who really studies the elementary parts of tissues and investigates the changes which occur as the bioplasm passes through various stages of change until the fully developed structure results, will be careful not to accept without due consideration the vague generalisations of those who persist in authoritatively declaring the dogma that the changes occuring in cell growth are merely mechanical and chemical, although they are unable to produce by any means at their disposal a particle of fibrine, a piece of cartilage, or even a fragment of coral. They avoid the difficulty as regards the bioplasm by ignoring its existence, and attribute to a "molecular machinery" which the mind cannot conceive, and which cannot be rendered evident to the senses, all those wonderful phenomena which are really due to vital power.

113. Nutrition of an elementary part.—We may now discuss what goes on during the nutrition of a "cell" when it is in a living state. I need not repeat that the *active* changes are exclusively confined to the bioplasm, and that the formed material is passive, though it may act like a filter, permitting some things to pass and interfering with the passage of others. Well, then, in nutrition, pabulum becomes bioplasm to compensate for the bioplasm which has been converted into formed material. Now, let us consider the order of these changes, and endeavour to express them in the simplest possible manner. Let the bioplasm which *came from pre-existing* bioplasm be called a; the non-living pabulum, some of the elements of which are about to be converted into bioplasm shall be b; and the non-living formed material resulting from changes in the bioplasm, c. It is to be remarked that b does not contain c in solution, neither can c be made out of b, unless b first passes through the condition a, and a cannot be formed artificially, but must come from pre-existing a. In all cases b is transformed by a into a, and a undergoes conversion

into *c*. Can anything be more unlike chemical and physical change? Neither *a*, nor *b*, nor *c* can be made by the chemist; nor if you give him *b* can he make *a* or *c* out of it; nor can he tell you anything about the "molecular condition" or chemical composition of *a*, for the instant he commences his analysis *a* has ceased to be *a*, and he is merely dealing with products resulting from the death of *a*, not with the actual living *a* itself. No wonder then that chemists and physicists persist in ignoring *a*.

114. Of the increase of Cells.—Several distinct modes of cell increase or multiplication have been described, but in all cases the process depends upon the bioplasm only. It is this which *divides*: and it is the only part of the cell which is actively concerned in the process of multiplication. It may divide into two or more equal portions, or give off many buds or offsets, each of which may grow as a separate body as soon as it is detached.

The formed material of the cell is perfectly passive in the process of increase and multiplication. Even the apparently very active contractile tissue of muscle has no capacity of increase or formation. If soft or diffluent, a portion of the formed material may collect around each of the masses into which the bioplasm has divided, but it does not grow in or move in and form a partition, as has often been stated, § 175. When a septum or partition exists, it results not from "growing in," but it is simply produced by a portion of the bioplasm undergoing conversion into formed material of which the partition is composed.

115. Cuticle or Epidermis.—The most external texture of the body, the cuticle or epidermis, is composed entirely of cells or elementary parts, some of which are being constantly removed from the free surface, while new ones grow up from below. In the cavity of the mouth, on the tongue, and lining the fauces, epithelium will be found, which, although

closely resembling that of cuticle, is softer and much more easily investigated.

At an early stage of development it is not possible to distinguish the masses of bioplasm which are to form the cuticle from those which take part in the development of the true skin with its nerves and vessels, glands, hair, and adipose tissue. And at the deep part of the cuticle, even in old age, will invariably be found numerous naked masses of bioplasm, which exactly resemble those present at a very early period of development, § 45.

116. Examination of Adult Cuticle.—Suppose we examine carefully a portion of adult cuticle. The oldest part of this structure is on the outside, and the youngest, or that which has been most recently formed, is situated nearest to the blood, whence the elementary parts or cells draw their nutritive supply. If we make a perpendicular section of this structure and place it under the microscope, we shall find that in different parts of it the "cells" present very different characters. The deep portion which is nearest to the vessels consists of small masses of bioplasm, surrounded only by a trace of very soft formed material. These are situated very close to one another. A little above this the masses have a more definite arrangement, and each oval mass of bioplasm, now grown larger, § 117, is surrounded by a thin layer of formed material like an external membrane. Still nearer the surface the elementary particles are seen to be larger, both bioplasm and formed material having increased in quantity. As we approach the free surface, the cells become more or less flattened, and the bioplasm is much reduced in proportion. The formed material is harder and more condensed. Lastly, the oldest elementary parts upon the surface, which are rubbed away in great numbers, and possess no bioplasm whatever, seem to be composed entirely of cuticular substance or formed

material. They have ceased to grow, and are no longer *capable of growth.* They are dead.

117. Bioplasm in Cuticle of different ages.—If equal portions of the most superficial and deepest strata of cuticle be taken, the proportion of bioplasm to the formed material will be found much less in the former than in the latter. At the deep aspect, where the elementary parts are being produced, the *bioplasm is abundant.* Upon the surface, where only old ones, which are about to be cast off, are found, *the bioplasm is reduced to a minimum, or has altogether disappeared.* Consider how these particles of cuticular epithelium grow. Here is a little mass of bioplasm which grows and then divides into two; each of these subdivides, and so on. Now, each of these little bodies absorbs nutriment from the surrounding fluid. It increases in size. The older particles on its surface are altered, and appear to be converted into a hard substance, which is improperly described as a membrane (cell-wall). As it approaches the surface, the hard material, cuticle, deposited layer within layer, becomes thicker and thicker, until at length the mere trace of bioplasm which remains in the centre, being too far removed from the source of nutritive supply to increase, perishes; and the elementary part, in the form of a flattened scale of dry cuticle, having by this time reached the surface of the body, is cast away, while its place is taken by others which grow up from below.

118. Hair, horn, nail.—Hair, horn, and nail are epithelial structures, and if we examine the cells or elementary parts at the bulb, base, or growing portion, we shall invariably find numerous small masses of bioplasm like those situated at the deep aspect of cuticle. It is in this situation that the bioplasm divides and subdivides, and the new cells which are formed push before them those previously developed. In the fully formed hardened cells of these structures the bioplasm has completely disappeared, but in

those near the growing part it can always be readily demonstrated by the aid of the carmine fluid, § 68. The structure and mode of growth of these tissues are well illustrated in the long, ragged, hair-like process found upon the summits of the filiform papillæ in the central part of the dorsum of the human tongue, for the individual cells can be distinguished in almost every part of the hair-like process; and as they are not closely matted together, as in the hair, nail, and horn, their arrangement can be very satisfactorily demonstrated. These hair-like processes can be obtained by slightly scraping the dorsum of the tongue with a knife. The bioplasm can be seen, not only in the young growing cells at the base, but in those that are mature in the lower part of the shaft, and with a little management the constituent cells can be isolated from one another and examined separately. In many of my specimens the bioplasm is beautifully distinct and well coloured by the carmine fluid, while numerous new centres (nucleoli) can be discerned which are more intensely coloured than the rest of the bioplasm. The formed material is perfectly destitute of any colour whatever. By examining structures of this kind, the student will be able to form an opinion concerning the great advantages to be derived from practising the staining process.

119. Epithelial textures hardened with calcareous matter.—I will now advert to the remarkable changes which occur during the formation of those very hard tissues which are infiltrated with calcareous salts, and in which the bioplasm plays a conspicuous part. In illustration, I will draw attention to the formation of two of the hardest and most durable textures in the body—the *enamel* and *dentine* of the tooth. Although, in their fully developed state, these tissues are remarkable for the large proportion of earthy salts they contain, there was a time when each was composed of very soft organic matter only. Although no trace of

bioplasm can be detected in the fully formed dentine or enamel of the adult, at an early period of development these tissues were represented by masses of bioplasm only.

Additional interest attaches to the consideration of the structure and growth of the enamel and dentine on account of the different and conflicting views entertained concerning their nature—some holding that enamel corresponds to the epithelial textures we have been considering, while it is maintained that the dentine is more nearly related to bone and the connective tissues. According to this view, the neutral line between the two represents the position of the basement membrane in an ordinary mucous membrane. Huxley, on the other hand, and for reasons which seem to me insufficient and unsatisfactory, holds that both enamel and dentine are *dermal tissues*, and *situated beneath basement membrane.* Lastly, the position of the vessels as regards the dentine, the manner or growth of both tissues, and the fact of their origin in a collection of unquestionable epithelial cells, have forced me to conclude that *both enamel and dentine are more nearly allied to epithelium than to any other tissues of the body, and that both are developed on the surface of basement membrane.* The tooth grows in a manner so like a horn and a hair that it is difficult to believe that is is not closely related to these epidermic appendages, while there are not wanting instances in which an eminence covered with an epithelial texture seems to take the place of a tooth. Hair and teeth are sometimes abnormally developed, and Mr. Darwin has remarked that the teeth of hairless dogs are defective, and that over-hairy men have abnormal teeth. My own conclusion upon this matter, after examining with great care the tooth at a very early period of development is, that the masses of bioplasm concerned in the formation of the enamel and dentine are embedded in epithelium and are arranged in two

curved lines, one within the other. The slight interval between these lines corresponds to the line of junction of the enamel and dentine in the fully formed tooth. From this *neutral line* the masses of bioplasm of the two rows move in opposite directions. In the outer one each mass diverges outwards from the neutral line while the different masses of bioplasm of the inner row converge slightly as they move inwards and form dentine in their wake.

120. Formation of Enamel.—The formation of the enamel may be very successfully studied in the canine tooth of a young pig. In one of my preparations, obtained from an injected specimen, the capillaries of the enamel membrane are seen to be well injected with transparent blue injection, and the enamel cells, the bioplasm of every one having been well stained with carmine, are distinctly shown. Each appears as a columnar or cylindrical body, not unlike a cell of columnar epithelium, with an oval mass of bioplasm nearest to its distal extremity. As the bioplasm moves outwards from the neutral line above referred to, it forms the column of soft material which is to become the enamel rod. After some extent of soft tissue has thus resulted, calcareous matter is deposited in that part of the column which was first formed. In my specimen several columns can be discerned in which the change has already commenced. The highly refracting earthy particles contrast remarkably with the smooth, faintly granular, organic matrix. The deposition of these earthy salts may be due merely to chemical change consequent upon the formation of free alkali in this the oldest part of the organic matter. While this process is going on, the bioplasm in each little column is still moving outwards, and forming more organic matter, which, in its turn, becomes calcified. This process continues until the formation of the enamel is complete, when the vessels of the membrane waste. A

little uncalcified organic matter usually remains upon the outer surface of the enamel. The markings seen in a transverse section of enamel receive a simple explanation upon this view of the development of the tissue. The outer uncalcified portion of the rods, when acted upon by acetic acid, swells up; and the appearance as of a membrane covering the enamel is produced. Some have been led to the conclusion that an actual membrane (basement membrane) or membrana preformativa, actually existed in this situation. Consult Mr. Tomes's "Dental Surgery," p. 268.

121. Formation of Dentine.—The dentine of the tooth begins to form before the enamel. But very soon after the formation of enamel has commenced the two operations go on together until a short time before the tooth emerges from the gum. The production of enamel is then completed, while that of dentine continues more slowly as age advances, but the development of this tissue does not cease in some cases before a considerable age is reached. In certain instances—as, for example, in the case of the canines of some of the lower animals and in the incisors of the rodents—the formation of both structures continues through life, so that in the teeth of the adult the development of the enamel and dentine may be studied as well as during the very early period of life in other cases. The oval masses of bioplasm taking part in the formation of the dentine are larger than those of the enamel, and the formed material produced by them appears as a continuous matrix rather than as distinct and separate columns. Moreover, instead of each mass forming a separate oval body, a thin line of tissue is drawn out as the dentine bioplasm moves inwards. These lines of soft tissue correspond to what are generally termed the dentinal tubes, and may be forcibly withdrawn where the process of calcification is nearly completed. In thin sections the corresponding "tubes" from which the processes

of soft tissue have been withdrawn may be also demonstrated. Calcification takes place by the deposition in the matrix of rounded globular masses of calcareous matter, which increase in size and ultimately coalesce. A narrow portion of the matrix extending outwards from each mass of bioplasm still remains permeable, and the process of calcification proceeds so much more slowly in this portion than in the rest of the matrix that the dentine produced refracts differently, and is harder in texture.

122. Of Dentinal "Tubes."—The difference in refraction above referred to and always noticed in thin sections has led observers to regard this more slowly formed layer of dentine as the "wall" of the supposed "tube." But in the recent state this "tube" is occupied by uncalcified matrix, which can be torn away from the already calcified dentine. The calcification of the formed material corresponding to the "tube" gradually proceeds, so that the space or "tube" occupied by soft matter becomes narrower as the dentine advances in age, and at last in many cases the outermost portion becomes completely calcified, in which case there is no "tube" at all. The "dentinal tube" of the dry prepared specimen results from the desiccation of the uncalcified organic matter of the recent structure. The greater "width" of the tube near the pulp, and its gradual reduction in diameter towards the surface of the dentine; the existence of soft solid matter in the "tubes," as was first demonstrated by Tomes; and the relation of the oval masses of bioplasm on the surface of the pulp to the dentine, are all accounted for in the explanation of the development and formation of the dentine above given.

123. Dentinal "Tubes" not canals for conveying fluid.—Is it reasonable therefore to suppose that the dentinal tubes are really channels for the conveyance of nutrient fluid from the surface of the vascular pulp

to the dentinal tissue, as has been so long taught? There are no tubes fulfiling a similar office in ivory—a tissue very analogous to the dentine. Surely, if the ivory of the elephant's tusk can be formed and preserved in a healthy state without nutrient fluids being conveyed by tubes to every part of it, it is extremely probable that the dentine of other mammalian teeth is in like manner destitute of any such special provision, as has been conjectured, for its free irrigation in every part. These tissues really undergo little change after their formation, and such an extensive system of nutrient channels as has been supposed to exist would be perfectly useless.

The formation of the soft tissue of dentine and enamel affords an interesting example of the growth movement in *opposite directions* of masses of bioplasm destined to produce special structure. In each case the bioplasts move towards a vascular tissue which recedes as they advance, and which wastes when the formation of the tissues and their calcification have been completed.

124. Of Secreting Cells.—Contrasting in most important particulars with the epithelial cells of the mouth, already referred to in § 33, are the "cells" which are concerned in the formation of secretions, of which the *liver cell* may be taken as an example. This elemental unit consists of a spherical mass of bioplasm, often containing new centres of growth (nuclei), surrounded by a considerable extent of soft formed material, giving to the whole an irregularly oval or somewhat angular appearance. Sometimes there are two or even three masses of bioplasm in one "cell," in which case the mass looks more like a portion of a cylinder than a "cell." The formed material is undergoing change upon its outer surface, and, although resulting from changes in one kind of bioplasm, becomes gradually resolved into sugar and

amyloid, *fatty matter*, *the resinous salts of the bile*, and *colouring matters*.

125. Flask-like Secreting Cells.—Another type of secreting cell is that in which the secretion is poured into the interior, and, after accumulation, discharged from a free opening at its extremity, the cell remaining for some time a fixture, and continuing to discharge its office. In the mouth of the boa these cells attain a very high degree of development, and are of large size. They also exist in great number, and some may be found in every stage of formation; for, although each one may perform its work for a certain period of time, the cells are being continually removed and replaced by new ones which grow up from below.

Like all other elementary parts or units, these flask-like cells exist first as spherical or oval masses of bioplasm, which then become altered upon the surface, and the formed material constituting the "cell wall" is produced. In this cavity products resulting from the change of the bioplasm at its distal extremity accumulate, and the cavity becomes dilated. The accumulation of contents and enlargement of the space proceed till at last the summit of the cell approaches the surface; an opening is then formed at its free extremity, and the contents are discharged. These cells remain for some time in position, constantly discharging the secretion which is being formed by the bioplasm in their interior. The bioplasm remains near the lower attached extremity of the open-mouthed cylindrical cell, and takes up nutrient matter at its lower surface, while at its upper part, which forms the floor of the cell cavity, the bioplasm is gradually changed into the *secretion* of the cell. This accumulates in the cavity, and gradually escapes from the open orifice. A large quantity of pabulum may pass into the state of bioplasm, and a corresponding quantity of the latter

undergo conversion into the formed material or *secretion* of the cell, while the entire apparatus hardly changes in volume or alters in form or weight.

126. Formation of different products by the same Bioplasm.—The above is an interesting example of a mass bioplasm giving rise successively to two different products. It first produces the cell wall, and then gives rise to "products of secretion," the composition and properties of which are entirely different from it.

I will now refer to one or two other cases in which substances differing in composition and properties from the "cell wall" are formed from the bioplasm within the cell.

127. Fat Cell.—The fatty matter of the fat cell is formed by the bioplasm after the vesicle or wall of the cell has been produced on its surface. The changes may be studied in the adipose tissue of the white mouse, frog, or other small animal. In the chameleon and many other animals, instead of one globule of oil being formed, and then increasing gradually in size, several minute oil globules result and these accumulate in the cell. Beautiful specimens of fat cells at every stage of development may be obtained from the connective tissue of the frog and newt.

128. Starch Cells.—Closely resembling the process of formation of fat in the fat cell is the deposition of starch in the starch cells of many vegetable tissues—as, for example, the common potato. If the gradual changes which take place as the bioplasm becomes developed into the mature starch-holding cells be studied, the following observations will be confirmed.

Little insoluble particles of starch are seen embedded in the bioplasm of the very young cells. These particles increase in size by the deposition of more insoluble starchy matter layer after layer upon their surface, as in the formation of a calculus until the starch-grains assume the perfect form.

129. Secondary deposits.—In some of the cells of the potato the cell wall is thickened by the deposition of "secondary deposits," in which case no starch granules are usually produced. This thickening occurs only at certain points, leaving slight intervals, through which currents of fluid continue to flow to and from the bioplasm in the centre of the cavity. The process may continue until the secondary deposit reaches near to the centre of the cell. The channels for access of nutrient fluid to the bioplasm in the centre remaining open, give to the mature cell the stellate appearance familiar to every one who has examined such "vegetable cells."

Just as the "secretion" in the peculiar flask-like epithelial cells in the mouth of reptiles results from changes in the bioplasm already described, so it may be said the peculiar "contents" or "secondary deposits" of other cells are "products of secretion," and that they correspond to "tissue" in other cases. They are all *non-living* substances, resulting from change in bioplasm, and they constitute different kinds of "formed material." The numerous pigment granules in the large stellate radiating and freely communicating pigment cells of the choroid coat of the eye, and those found in various parts of the frog, afford another example of a peculiar material resulting from change in the bioplasm. The formation of pigment commences at a very early period of development, and its abundance seriously interferes with the investigation of the structure and growth of the tissues of these animals, in other respects so well adapted for the purpose.

130. Of Ciliated Cells.—The cilia of ciliated cells, like the outer part of the cell, the so-called cell wall, are composed of *formed material;* but the movements of these hair-like processes are due to changes taking place in the bioplasm or living matter. The vibration of the cilia ceases when the bioplasm dies,

and is generally influenced by any alteration in external circumstances which exert an effect, favourable or unfavourable, upon bioplasm. The proportion of bioplasm or living matter in ciliated cells is considerable, and its relation to the cilia is such as to favour the view that it is intimately concerned in the movements. Nutrient matter is taken up by the mass of bioplasm upon the side opposite to that nearest to the cilia, and it seems probable that the production of formed material, and a consequent alteration in the tension of the texture of which the cilium is composed, accompanies each movement. I think that the rate of vibration enables us to measure the rapidity of nutrition, and that the to-and-fro movement marks the change of pabulum into bioplasm, and the latter into formed material. This change, which in many cases is probably continuous, here gives rise to an interrupted movement, perhaps because the elastic porous tissue of the cilium suddenly expresses from its meshes the fluid which had just previously passed into them from the bioplasm.

An objection has been raised to the view I have advanced, on the ground that the part of a cilium of ciliated epithelium which dies first is the base, or that part which is nearest to the living bioplasm, not the apex which is most distant and which is undoubtedly the oldest part of the cilium and that which was first formed. This argument which has been advanced by Prof. Rutherford, would have been regarded by me as of great importance if it had been proved that the cilium itself was bioplasm or living matter. But so far from this being the case, it is almost certain that the cilium is composed of lifeless passive formed material, the movements of which are caused by the changes effected by the living bioplasm at its base. Now, it is obvious that an impulse forcible enough to produce even considerable movement of the thin free extremity of a cilium

might be altogether insufficient to effect the slightest motion in the thicker basal portion connected with the surface of the cell, and in very close relation with the bioplasm. In this way we may explain the fact of movement ceasing first at the base of the cilium without resorting to the hypothesis of gradual death from base to apex in a structure which is probably not alive, and the movements of which are not vital movements, but rather the consequence of vital changes in living matter immediately adjacent to it. Cilia are indeed modifications of formed material,—of tissue or of cell wall.

131. Pigment Cells.—In various parts of the frog, newt, and other batrachia are numerous very large and branched cells containing fluid, in which are suspended multitudes of very minute particles of pigment formed from the bioplasm of the cell which is situated in the central part, and is usually obscured by the quantity of pigment present. As in other cases, currents of fluid set *to* and *from* this mass of living forming bioplasm. The radiating tubular prolongations of the cells communicate with one another, and are sometimes filled with fluid having the pigment granules evenly diffused through it, while sometimes the minute dark granules become aggregated round the bioplasm in the centre of the cell, and the radii are destitute of them. The movement of the visible particles of pigment results from the movements of the invisible fluid, which at one time fills the cavities and tubular prolongations of the cells, and at another permeates the delicate walls, and becomes diffused into the surrounding textures. When the tissues are saturated with fluid, the radii also contain it, and the pigment spreads into the tubular network, but in the opposite condition the particles become aggregated in the centre of the cell, and the walls of the tubular processes approach one another. The opposite conditions of saturation of the tissues with fluid and its

removal, are determined by the altered states of capillary circulation, which are themselves dependent upon the degree of contraction of the small arteries which carry the blood to them; and this is affected by the changes in nerve centres from which the arterial nerves are derived. In this way, I think, may be explained the concentration and diffusion of the pigment in these remarkable cell spaces and channels, which formed the subject of a highly interesting memoir by Professor Lister, who, however, inferred that the nerves exerted some *direct action* upon the diffusion of pigment. In order to make this view appear plausible he was, however, obliged to assume the presence of an "apparatus, probably ganglionic in structure, co-ordinating the action of the pigment cells,"* which neither he nor any one else has been able to discover, and the existence of which is for many reasons most doubtful. The fact is easily explained by the alteration in the amount of fluid traversing the tissues at different times. When the circulation is diminished or arrested, the fluid in the cells passes into the tissues, the tubes become nearly emptied, and the walls in apposition. The solid particles become concentrated in the large central cavity of the cell, which is the last part to lose its fluid; but when the circulation is free, and the tissues are abundantly irrigated, the particles spread into the radiating tubes now filled with fluid. Professor Lister himself remarks that *post-mortem* secondary diffusion occurs in a piece of web "cut out and placed in a drop of water on a plate of glass." Instead of accounting for this fact by the changes resulting from the imbibition of water, he invents an explanation which I must venture to say does not appear to be justified by observation or experiment, attributing it to the action of hypothetical nerve cells "disseminated among

* "On the Cutaneous Pigmentary System of the Frog." Phil. Trans., 1857.

the tissues of the web itself." But even if we were to assume the existence of such a system of nerve cells and fibres, we should be unable to account for the change unless Mr. Lister or some one else could explain how such an apparatus would cause little particles to move to and fro in fluid contained in the interior of a cell; but we should have to add hypothesis to hypothesis before we should arrive at a plausible solution of the fact, while, on the other hand, a much simpler explanation is afforded without supposing direct nervous action at all. The currents setting towards the mass of bioplasm in the centre of the cell, and the varying quantity of fluid diffusing through the tissues under varying degrees of vascular distension, which we know actually do occur, fully account for the phenomenon. These pigment particles which we see actually moving prove to us the existence of currents of fluid through tissues to and from the masses of bioplasm. We may be sure that similar changes occur in other tissues, and that in the perfectly transparent anastomosing stellate cells of the cornea, for example, corresponding alterations are continually occurring during life.

132. Salivary Corpuscles.—Another striking example of movement resulting from changes in the bioplasm or living matter is seen in the rapid movement of little particles in the fluid or semi-fluid material of which the salivary corpuscle is in great part composed. Owing to the constant disturbance of the fluid caused by the currents flowing to and from the actively growing living matter, the little particles suspended are kept in a state of constant agitation, now forced towards the surface, and then as rapidly whirled towards the centre, perhaps suddenly stopped and driven again in an opposite direction. These movements are very remarkable. The actively moving particles in the interior of the corpuscle can be seen with a good quarter of an inch

object glass, but they may be well studied by the aid of a twelfth magnifying 600 diameters.

The nature of the particles is still doubtful. They closely resemble in most of their characters the minute spores of fungi. Their motion, however, is not due to the particle itself, but is evidently secondary, resulting from the movement of the fluid in which they are suspended. It is possible these minute particles may be the agents concerned in the very rapid conversion of starch into sugar which the saliva is known to effect.

MICROSCOPICAL PREPARATIONS ILLUSTRATING LECTURE V.

	No. of diameters magnified.
19. Bioplasm taking part in the formation of epithelium and skin, with vessels, nerve fibres, and other structures	215
20. Epithelium of tongue and subjacent textures at birth	215
21. Epithelium of tongue, old man aged 74	215
22. Papillæ of tongue, vessels injected, covered and uncovered with epithelium, adult	130
23. Epithelium, mouth of kitten one day old, showing bioplasm and formed material	215
24. Epithelium, mouth of chameleon, showing large mass of bioplasm (nucleus) with new centre (nucleolus)	215
25. Hairs from surface of tongue, human subject ..	130
26. Hairs and hair bulbs from skin of the kitten. Observe the great quantity of the bioplasm at base of the bulb where the new growth takes place ..	40
27. Hair, vessels, nerves, and adipose tissue; ear mouse..	215
28. Dentine and enamel, human tooth	130
29. Bioplasm and prolongation torn from the calcified dentine, with "dentinal tubes"	700
30. Enamel cells, pig at birth	215
31. Bioplasm of periodontal membrane, showing beautiful stellate masses, freely anastomosing	215
32. Liver cells, toad; in tubes of basement membrane..	215
33. Epithelium from mouth of snake, showing large flask-like cells, from the orifice secretion escapes ..	400
34. Ciliated cells from branchiæ; oyster..	215
35. Pigment cells, frog; showing pigment granules ..	130
36. Salivary corpuscles showing moving granules within.	700

LECTURE VI.

Formation of Tissue—Of Epithelial and Fibrous Tissue—Formation of Spiral Fibres—Contractile Tissue—Nerve Tissue—Formation of Fibrous Tissue in healing of a Wound—Simple Fibrous Connective—Increase in Old Age and in Disease—Mode of increase in Muscles and Nerves—No Fibrous Connective in Insects—Skeletons of young Organs in the Adult—Interruption of Normal Changes—Vitreous Humour—Mucous Tissue of Umbilical Cord—Connective Tissue—White Fibrous Tissue—Repair—Bioplasm of Cornea—Bioplasm of Yellow Elastic Tissue—Ligament of the Neck of the Giraffe.

THE *tissues* of which the internal organs of animals are composed vary remarkably in structure, composition, and properties. We find various gradations of resistance and density, from a texture of such extreme tenuity as to be scarcely demonstrable, to the firm, fibrous, cartilaginous, and osseous tissues, the hardness of which renders their investigation difficult. All tissues are, however, formed from masses of bioplasm alike in general characters, though differing vastly in power.

133. Formation of Epithelial Tissue and Fibrous Tissue.—By many the formation of structures like epithelium has been looked upon as a process distinct from that which results in the production of fibres. In classifying the tissues, attempts have been made to show that those textures which were composed of multitudes of "cells," were of a different nature to those which exhibited a "fibrous appearance." More careful investigation has proved that these ideas must

be abandoned, and that the formation of all tissues is characterised by changes of the same kind. Whether soft, smooth, structureless material, or firm, resisting fibrous texture is to be formed, the change is effected by a mass of bioplasm which could not be distinguished from the bioplasm which produces any other kind of formed material. Not only so, but a given mass of bioplasm may, under certain circumstances, form upon its surface a capsule, and so ultimately produce a cell-form, while, under other circumstances, this same mass may form a distinctly fibrous structure, or a firm matrix, having no definite structure whatever. Moreover the bioplasts which are to form the cuticle of the embryo and those which are to produce the fibrous texture of the skin, lie so very close together that no one could say which would take part in the production of one texture and which of the other. They are not separated by any line of demarcation or membrane, and both sets of bioplasts have the same origin. In the process of healing of a wound near the surface of the body, "lymph" is poured out in which may be found bioplasts which have descended from white blood corpuscles. Of these, some produce epithelium, others fibrous connective tissue, unless they be too freely nourished, in which case they grow and multiply rapidly, and no kind of tissue whatever results, but pus § 43 is alone formed.

134. Formation of Fibres.—Fibres may be drawn out, as it were, from any mass of bioplasm in one, or in two or more directions. The mass of living matter may then assume an oval, spindle-shaped, or stellate form. *Thin structureless expansions* may be produced directly by bioplasm, or fibrous-like membranes may be formed. The "fibres" may run parallel, or may cross at various angles, giving rise at last to a tissue of such extraordinary complexity that it seems almost hopeless to endeavour to unravel it, and impossible to find out how fibres, running in so many different

directions, were developed. By careful examination, however, at different periods of the development of such a tissue, the observer will, in some cases, be able to form as clear a conception concerning the manner in which the interlacing fibres were deposited, as he may gain of the mode of formation of a complex spider's web, by careful examination at short intervals during its formation, although he has not witnessed the creature actually at work. So delicate are the fibres in some tissues that they can only be detected by resorting to artificial colouring; and careful investigation leads me to think that in many cases in which a tissue appears perfectly homogeneous and structureless, it is really composed of excessively fine fibres, which cannot be clearly demonstrated by the aid of the methods of investigation at our disposal.

135. Movement of Bioplasm in all tissue-formation.—The peculiar characters and arrangement of some structures can be accounted for by the movements of the bioplasm during their formation, and conversely we may learn much concerning the movements of bioplasm by a minute and careful investigation of the arrangements of the elementary tissue which has been formed by it. In the formation of the elastic cartilage of the *epiglottis*, for example, it seems probable that each mass of bioplasm revolves while it forms delicate fibres, which accumulate, and at length appear to be arranged concentrically round the space in which it lies. The fibres, in this case, seem to be formed somewhat in the manner in which the caterpillar spins its cocoon, except that in the case of the tissue, the process is interrupted, while the last is a continuous operation. The attachment of the bioplasm to some of these fibres may be distinctly seen in the particular texture referred to.

136. Remarkable spiral Fibres.—In connection with the ganglion cells of the sympathetic of the frog, I have described a very remarkable spiral

arrangement of nerve fibres, which can be readily explained by supposing movements of the bioplasm, while I believe in no other manner can the facts be satisfactorily accounted for. So also by the careful study of the arrangement of the twisting of nerve fibres in many tissues, we shall become convinced of the never-ceasing movement of the masses of bioplasm, not only during development, but afterwards, during the adult period of life. In this way only can many of the highly intricate structural arrangements, familiar to us in many organs of man and the higher animals, be explained.

137. Changes in Tissue after formation.—Changes, however, take place in many kinds of tissue after the formative act has been completed. In some cases the part which was first produced dries up, and gives rise to irregularities or cracks, which appear as peculiar markings, and may be characteristic of the fully formed structure. Sometimes a tissue, which for a long time may appear homogeneous and clear, gradually acquires a fibrous appearance from the tendency of the old tissue to split, or cleave in certain directions, which will, in fact, be found to correspond to the lines in which new tissue material was deposited at an early period of formation.

138. Epithelial Tissue.—One of the simplest forms of tissue found in man and animals, and perhaps that which is produced most easily and most quickly, is cuticular epithelium, § 115. Possessing elasticity, and considerable extensile property, performing the passive office of protecting more important textures beneath it, upon which it rests, and with which it is often connected, this tissue is readily replaced, if removed, and when injured is quickly and effectually repaired. Epithelial tissues exhibit, however, remarkable differences in property in different situations. One may be dry and firm, hard and resisting, forming a sharp point or cutting edge, as in certain kinds of

nail and horn; another may be supple and elastic, like the epidermis, or soft and moist, like the epithelial tissue of mucous membranes and internal passages, while some forms of epithelial tissue are semi-fluid, or more or less viscid, of the consistence of mucus, § 34.

139. Different kinds of Epithelial Tissue.—The student would scarcely believe that the soft, moist epithelium of a mucous membrane was in any way related to the hard dry tissue of which nail, horn, and hair, § 118, consist, or to the hard calcified texture of shell, dentine, § 120, or enamel, § 121; but if he were to examine these textures at an early period of their development he would be convinced of their very close relationship, and would find that the formed material was produced in the same manner in them all. It may be truly said that one thing can scarcely differ more from another than the soft, moist epithelium of a papilla of skin or mucous membrane does from the firm cuticular tissue of horn or hair, and yet under modified conditions the former may become so altered as to constitute a tissue which any one would admit was closely allied to the latter structures. The fibre-like cells constituting certain forms of hair, horn, and nail are very different from other forms of epithelial tissue, but, as is well known, well-developed horns are occasionally produced on the skin, and the horny material consists but of modified epidermis. The long drawn out cells or fibres of enamel and dentine are probably modified forms of epithelium, the formed organic matter of which has been gradually impregnated with calcareous particles, § 119.

140. Difference in function discharged by Epithelial Tissues.—Nor do epithelial textures differ from one another less remarkably in structure and physical properties than they do in function. The cell which secretes bile, or urine, or gastric juice, § 124, would seem to be very far removed from the epithelial cell

of the cuticle or of a mucous membrane, for the former are instrumental in the production of secretions possessing very peculiar properties and containing much water, while the last produces only the dry horny matter which accumulates, or a softer material which, however, by gradual drying, may be converted into the same sort of passive substance. The relationship is however distinctly seen in disease, for there are conditions under which secreting cells may cease to produce their characteristic secretions, and shrivel up and waste, becoming at last so changed that some of them might easily be mistaken for a very simple form of non-secerning cell structure. While in "inflammation" the bioplasm of all these cells being supplied with an undue proportion of nutrient material, gives origin to a common form of bioplasm—"pus."

141. Gland follicles and ducts.—A gland follicle itself, with its included epithelium, is, in the first instance, but a diverticulum from the duct; which duct is but an inflection of the general surface. In the formation both of the duct and the gland follicle epithelium is instrumental. Young cells may grow in a direction *from* the duct, and multiplying in number may produce a little collection like that seen in the gland follicle, or a long series may result, as in the formation of the tubes of which some glands are constituted. Eventually the permanent epithelium of the secreting part of the gland differs so much in form and action and properties from that of the duct, that, had we not watched the evolution of both, we should not have been inclined to believe in their common origin.

142. Formation of epithelium and fibrous tissue by bioplasm.—At an early period of development no structural differences can be discerned between the formed material produced by those masses of bioplasm on the surface of the body which are to give

rise to "epithelial cells," and that formed by those beneath which are to take part in the development of "fibrous tissues," "vessels," "nerves," and "muscles." But gradually the soft mucus-like formed material first produced, disappears, and *tissue*, exhibiting peculiar structure, and manifesting special properties, is slowly formed by the bioplasm. This constitutes the *tissue* of the epithelial cell, or the fibrous tissue of the subjacent textures, as the case may be. The process of epithelium formation on the surface having commenced, continues as long as life lasts, and the loss of the old epithelial cells is compensated by the production of new ones beneath.

143. Formation of contractile tissue.—One of the most remarkable examples of peculiar structure familiar to us, and one which cannot be at all satisfactorily explained at present, is striated muscle. But we must not conclude that the transverse markings are essential to contractile tissue, for they are completely absent in the case of involuntary muscular fibre. While, on the other hand, there are certain kinds of fibrous tissue, destitute of contractility, which possess distinct transverse markings. Nor are the striæ of muscle seen at an early period of development. They do not make their appearance until *contraction* of the tissue has repeatedly occurred; but the fact of their great regularity and constant uniformity in the same species of animal precludes the possibility of these markings being due merely to some accidental variation in the refractive power of the muscular tissue. It is certain they depend upon the occurrence of important structural changes while the contractile material is in a very soft plastic state. They may be due to the rate of formation of the contractile substance, and the rapidity of the successive actions of the nerve current instrumental in exciting contraction. The depth of the contracting portions indicated by the varying distances between

[illegible]

144. Formation of nerve tissue.—[illegible]

145. Formation of [illegible].—[illegible]

[illegible]

or combined with it at the time of its origin from the bioplasm. The gradual production of these fibres may be studied under the microscope during the coagulation of a drop of *liquor sanguinis.*

146. Formation of cuticle during the healing of a wound, &c.—A modified form of cuticular tissue may be produced in a manner different from that described in § 116. Where the healing process proceeds over an extensive surface after the removal of a considerable portion of skin, new cuticle is at last formed. The formation of new cuticular texture does not only spread gradually towards the centre of the space from the intact cuticle at the margin of the wound, but new points of cuticle formation are seen to originate as little islands even in the central part. This cuticular tissue must be formed by masses of bioplasm, which have descended from white blood corpuscles, many of which are usually found upon the surface of a healing wound, having escaped when very small with the serum of the blood through the thin walls of the capillaries.* It must be remembered that the particles of bioplasm concerned are the descendants of white blood corpuscles which have themselves descended from embryonic masses of bioplasm formed at a very early period of development before many of the tissues were formed, and at a time therefore when the capacity for the production of diverse structures was greater than at a later period. The white blood corpuscles are the only masses of bioplasm of the adult that could inherit the diverse powers of embryonic bioplasm, and this perhaps may be the explanation of the greater degree and variety of formative capacity possessed by these as compared with other living particles.

147. Formation of fibrous tissue in healing of wounds.—When a wound in the substance of a tissue

* "On the Germinal Matter of the Blood." Mic. Journal, 1863.

is repaired, fibrin is first formed from the minute bioplasts and white blood corpuscles. The bioplasm embedded in the meshes of this newly formed web of temporary tissue then grows and multiplies, and at length masses are formed from which a firmer and more lasting fibrous tissue results. This is deposited in definite layers, and in a definite direction, while the old temporary fibrin having served its purpose is slowly absorbed. The changes referred to have been carefully studied in the fibrin deposited from the blood in the repair of a wounded artery. The characters of the coagulum first formed, and the changes which take place in it afterwards, have been represented in the plates appended to the memoir referred to, "On the repair of Arteries and Veins after Injury," by Henry Lee and Lionel S. Beale. Medico Chirurgical Transactions. Vol. L.

148. Simple fibrous connective.—This very delicate texture, the simplest of all the tissues, is very widely distributed in man and the higher animals. Indeed there is scarcely a part of the body in which traces of it cannot be discerned. From the circumstance of its existing between the more important structural elements of higher tissues, and connecting them to one another, as well as to other tissues, it has been termed *connective tissue*. It has been supposed that this texture was designed to give strength and support to more important tissues, but it must be obvious to any one who examines any of the organs in question, that the various structural elements afford the most efficient support to one another, and are not in need of a special supporting frame-work of any kind. It is indeed very remarkable that such a view should have been entertained, as it is well known that at the time when the more elaborate tissue elements are softest, and therefore most in need of support, that is at an early period of their development, scarcely a trace of this connective is to be found, while, on the other

hand, when the textures have acquired considerable firmness, and possess resisting power of their own, this "supporting" connective tissue exists in very large quantity.

149. Increase of fibrous connective tissue in old age and in disease.—The intervening connective, instead of being of advantage to the special elements of the tissue, actually interferes with their action, and its accumulation corresponds with the deterioration of the organ in which it takes place. Old textures differ from young textures of the same kind in the greater proportion of connective tissue present, and this results from changes occurring in the normal structure. In many painful examples of chronic disease of important organs which come under the notice of the physician, the premature decay at a time when all parts of the body ought to be still in an active, vigorous state, is associated with abundance of connective, this being, in fact, the *débris* of the more important texture which has wasted.

150. Mode of increase of fibrous connective in muscles and nerves.—It is easy to understand how the connective tissue results during the development of textures in which the permanent type of structure is not manifested until several temporary textures have occupied the place of that which is destined at last to remain. These temporary textures gradually disappear, leaving a small quantity of what we call fibrous connective, and this collects, in most instances, at the outer part, because the formation of the new tissue takes place in a direction from within outwards. In studying the development of tissues, which consist of collections or bundles of fibres as, for example, muscular fibres, this point may be demonstrated very conclusively. The new fibres originate in the centre, and great differences in character between the outermost fibres and those situated further inward, will always be observed. From the first the masses of

bioplasm, situated most externally, only produce connective tissue, and the muscle itself results from the development of those occupying a more central situation. The same fact is noticed in the development of nerve fibres. The masses of bioplasm, situated at the outer part of the bundle, do not produce true nerve fibres, but from them is formed connective tissue only. Up to a certain period the formation of true nerve fibres may have been possible, but a sufficient number of perfect fibres having been developed within, the marginal fibres degenerated and took the low form of fibrous connective.

151. Formation of fibrous connective in glands.—But the nature of this connective, and the mode of its production, are very conclusively determined by investigating the changes which occur during the development of a gland of highly complex structure, like the kidney or liver of man and the higher animals. At an early period of development the cells concerned in the formation of the kidney, for instance, multiply and become arranged so as to form a cylindrical mass. By their division and subdivision this increases in length and circumference, at least during a certain period, in every part of its extent. At the deep or external portion of these cells, adjacent to the vessels, matter is slowly deposited in an insoluble form, and thus a thin membranous boundary corresponding to the outer limit of the future tube results, and this becomes extended as the cells grow, while at the same time it is increased in strength by the addition of new matter. Between the lines of masses of bioplasm from which the tubes are developed, and those which take part in the formation of vessels and nerves, are a few masses which are not concerned in the formation of any definite structure, but which perhaps take part in the production of a small quantity of intervening substance. The membrane becomes further modified by its relation to the

nerves and blood-vessels. These were very close to the cells at the earliest periods of development, and a very close relationship between them must be maintained throughout life, or the free action of the gland would be impaired. Moreover, as the gland which already actively performs its functions grows, new nerve fibres and new capillaries must be developed around the tubes. The position which a capillary or or an ultimate nerve fibre occupies at an early period will at a later time be the situation where a *bundle* of *nerve fibres*, or *small arteries* and *veins* must be placed. The structural changes involved in all these alterations are considerable. Old capillaries and nerve fibres must be removed as new ones are developed to take their place, and all the original gland cells will have disappeared probably long before the uriniferous tubes have acquired their fully formed characters. But these structural elements are not *completely* removed. There remains a small quantity of matter which cannot be taken up by the ordinary processes at work. This is no doubt capable of being removed like every texture in the body, but its complete removal would probably involve the destruction of the gland, while its almost complete removal permits of the continuous development of the latter, and does not interfere with its continuous action. The conditions of existence in the case of man and the higher vertebrata, with a few unimportant exceptions only, permit the very gradual but not absolutely complete removal and renovation of the tissues first formed. Hence, as we grow older the greater is the amount of connective tissue that accumulates.

152. No fibrous connective in insects.—In insects, the state of things is very different, and in their textures there is an almost complete absence of connective tissue. The organs and tissues of the larva are entirely removed, while new organs and textures of the imago, or perfect insect, are laid down afresh

and developed *ab initio*, instead of being built up upon those first formed. Such complete change, however, necessitates a state of existence during which *action* or *function* remains in complete abeyance. In the pupa or chrysalis period of life, functional activity is reduced to a minimum, and nothing is allowed to interfere with the developmental and formative processes. The new and more perfect being which is evolved does not probably retain a trace of the structure of its earlier and less perfect state. Although the elements of matter in the imago are, of course, those of which the larva was composed, they have been as completely re-arranged as they would have been had they been introduced into the organism of another individual altogether. Not only have the old tissues been utterly destroyed and new ones produced, but in many instances these new ones belong to a totally different type; and were it not that observation has taught us that they have been really evolved at different periods during the life of one and the self-same individual being, we should have concluded not only that they belonged to different species, but in many cases to species far removed from one another.

153. Skeletons of young organs in adults.—In vertebrate animals there is not an organ in the adult but retains, not only the form which it assumed at a comparatively early period, but some of the very same tissue which was active in early life remains in an altered but deteriorated state. Every adult organ may be said to contain as it were the imperfect skeletons of organs which were active at an earlier period of life. This material which slowly accumulates, clogs, and perhaps even in the most perfect state of things, slightly interferes with the free activity of the organ. If from any interference with the changes this unabsorbed *débris* accumulates in undue proportion, the action of the organ may be

very seriously impaired. It indeed soon grows old, while all the rest of the body may remain young. Its imperfect action deranges other processes of the body, and these react upon it until further action becomes impossible, and death results. The gradual but continuous and regular decay and renovation of an organ is normal in the vertebrate animal. The changes exhibit wonderful elasticity within certain limits, according to the demand for functional activity of the organ, but these limits, narrow in some, wide in others, cannot be exceeded without derangement and slow deterioration resulting.

154. Interruption of normal changes.—This continuous renovation of an organ and accumulation of the skeleton of its earlier periods of existence may, however, be almost suddenly interrupted. In those changes which lead to the formation of pus the removal of every texture is as perfect as during the pupa state of an insect, but the bioplasm constituting the pus corpuscles has no power to give rise to that which will take part in the development of new tissues, while that which takes part in the removal of the larval tissues during the pupa state does possess this power. When therefore in vertebrata this complete change occurs the organ is destroyed, but a new one is never developed in its stead. A part of a complex organ may be destroyed and removed, but it cannot be formed anew, so that in man the gradual or sudden destruction of a great part of an organ necessary to life cannot be repaired, although in many cases the patient may adapt himself to the altered state of things and live under the changed conditions. The above considerations afford, I think, an explanation of the formation of the so-called interstitial indefinite connective found in greater or less amount in all organs of all vertebrate animals, and of its increase as age advances. The more regularly, gradually, and perfectly the changes are effected, the smaller will be

the proportion formed, and the more slowly will it accumulate. When this is the state of things in all the organs of the body, health and longevity result. The opposite entails disease and too early death.

155. Vitreous humour.—This texture is so delicate that no structure can be demonstrated in it, even if examined under high powers. It contains so little solid matter, that 100 parts lose by evaporation upwards of 99. The tissue, however, probably forms a delicate web, in the meshes of which watery fluid is retained. At an early period of development numerous masses of bioplasm may be demonstrated in every part of the mass that is to become the vitreous humour, and from each one may be traced extremely delicate filaments, which may be followed for some distance, but are at last lost sight of from their tenuity. Fibres no doubt exist which are too delicate to be seen. As development advances, the adult vitreous masses of bioplasm become separated from one another by an increasing extent of delicate tissue, and many of them disappear. Some on the surface may, however, be detected even in the adult, and probably are concerned in the formation of new tissue at the circumference, as well as in certain changes occurring in disease, which may result in a complete alteration in the character of the vitreous.

156. The mucous tissue of the umbilical cord (the jelly of Wharton) is one of the simplest forms of fibrous connective tissue, and one well worthy of attentive investigation. Like the vitreous, it contains very little solid matter. Its mode of growth is interesting, and by studying it carefully, we may obtain very accurate information concerning one way in which interstitial growth and expansion of a tissue in every direction are provided for. In very young mucous tissue oval masses of bioplasm are seen arranged round small circular spaces. They divide and subdivide, and move in a direction outwards from the

centre of each space. From each a delicate fibre extends, which intertwines with the fibres from adjacent masses of bioplasm. The bioplasm increases at the circumference of each area, while the previously formed tissue remains in the central part. Thus it happens, when the tissue has grown to a certain extent, more or less circular spaces, occupied by a very delicate fibrous tissue, are seen free from any bioplasm whatever, while the latter exists only at the circumference. These spaces increase in diameter as the tissue advances in development. In this way growth takes place equably in all parts of the tissue.

The above appearances in the structure of the tissue may be well seen under a low power in sufficiently thin specimens prepared as I have described. When examined under a magnifying power of 700 diameters, each elementary part is observed to consist, 1, of the oval mass of bioplasm prolonged in either direction for a short distance, and exhibiting oil-globules in consequence of change having taken place after death; and, 2, of the delicate fibrous tissue externally, which may be torn and frayed out without difficulty.

157. Virchow's juice-conveying tubes.—The extensions of the bioplasm into the fibrous tissue have been mistaken for tubes, and it has been stated by Virchow that these tubes anastomose throughout the tissue, and constitute a system of channels for the conveyance of the nutrient juices. But it need scarcely be remarked, first, that the supposed channels do not in all cases anastomose; secondly, that they contain bioplasm and imperfectly developed formed material, not fluid, as has been supposed; and, thirdly, that nutrition is more perfectly carried on by the tissue itself being permeated everywhere by the fluid flowing to and from the bioplasm, than it would be by any system of nutrient tubes like that imagined to exist.

The juice-conveying channels, described by Virchow as so *necessary* for the distribution of nutrient matter to the tissues, thus receive very different interpretation. It is now more than ten years since the views here given concerning the supposed nutrient juice-conveying channels were advanced, and quite time that the question of fact were examined by other observers. It is manifestly detrimental to the interests of science that erroneous views should be repeated year after year, although they have been distinctly proved to be erroneous.

158. Connective tissue has formed the battle-ground of many a scientific conflict, and the most extreme views have been entertained concerning its nature. By some it has been regarded as one of the most important and necessary of tissues in the organism, and as contributing to the support of higher and more complex textures, and concerned in the distribution of nutrient material to them. It has been maintained that some parts of the nervous system consist almost exclusively of connective tissue; and this texture has long been regarded as a most important and necessary constituent of nerve organs. Indeed, some have affirmed this to be the tissue in which nerves *end*. But, in opposition to these views, a great array of most important facts has been advanced. In some of the lower animals remarkable for their elaborate and delicate textures, which one would think really do require support, no connective tissue is to be found, while in the higher animals and man, scarcely a trace of the texture is to be met with at a very early period of development when the tissues are very soft and delicate, and when, therefore, they are most in need of support; at this time also they require a vast amount of nutrient material distributed to them in the most perfect manner, but notwithstanding their necessities, this tissue, supposed to be necessary for the conveyance of nutrient matter to them, is absent.

159. Formation.—Moreover, the mode of formation of connective tissue is opposed to the above theoretical views. Connective tissue results in many cases during the growth of higher and more important textures. The intervals between nerves, muscles, and other tissues, and between the constituent parts of these tissues respectively, are occupied by connective tissue. When a tissue or organ is to be developed, its germ always originates from bioplasm occupying the centre of a collection of masses of bioplasm. As its development proceeds, the superficial masses of living matter are pushed further outwards; and, instead of taking part in the formation of the particular tissue or organ in question, their formative power is limited to the production of this indefinite fibrous or connective tissue.

160. Connective tissue formed during the waste and decay of organs.—As organs and tissues decay, much of their structure is removed, but a residuum which remains is known as connective tissue, the masses of bioplasm of which correspond in many cases to those of the original cells or elementary parts of the tissue or organ which has wasted. Nerves, muscles, the tissue of the brain and spinal cord, the glandular tissue of the liver, kidney, and other organs, may thus become converted into a texture which is exactly like connective tissue, a form of which may even be produced from white blood and lymph corpuscles. In all kinds of connective tissue the relation of the bioplasm to the fibrous tissue or formed material is the same. In disease the masses of bioplasm often increase in size and multiply in number, giving rise to new connective tissue, which is added to that which already exists. In this way the condensation and alteration in properties of the original texture may be effected.

161. Cord-like fibres in fibrous connective.—In many kinds of connective tissue, besides a delicate

texture closely resembling certain forms of white fibrous tissue, there are some fibres exhibiting the reactions of yellow elastic tissue. These fibres differ in character and number in different cases. Some of them consist of elastic tissue developed from nuclei or masses of bioplasm, as will presently be described. But in many cases these fibres are probably the remains of nerve fibres or capillary vessels which had been active at an earlier period of life, while, in some instances, they result from the prolongations of the bioplasm being converted into imperfectly developed fibrous tissue, which, like bioplasm itself, is not rendered transparent and caused to swell up by the action of acetic acid.

162. White fibrous tissue consists of a firm, hard, whitish material which becomes converted into gelatine by boiling. The toughness and resisting property of skin depend upon this tissue. The bioplasm of all kinds of white fibrous tissue may be shown to be continuous with the fibrous tissue or formed material. If a small portion of white fibrous tissue, as tendon, be examined at a very early period of development under a power of 200 diameters, it will be found that it is composed of oval masses of bioplasm, with a very little intervening fibrous structure. At a still earlier period of its existence, it contained a still larger proportion of bioplasm. As growth proceeds, the fibrous material increases, and the bioplasm relatively decreases, so that when it reaches its adult form the principal portion of the structure consists of fibrous material, and there is comparatively only a very small amount of bioplasm. To state this more clearly—In equal portions of young and adult tendon the proportion of bioplasm is very different. There may be five or six times as much in the former as in the latter. This important fact will be demonstrated quite easily if a piece of young tendon be contrasted with a portion from an old subject. The contrast be-

tween the two specimens in the proportion of bioplasm which corresponds to a given amount of formed material is very striking. (See the new edition of "Physiological Anatomy and Physiology of Man," Part II.) The formed material increases as the tendon is developed, and at the same time it undergoes condensation. The fibrous material is continuous with, and has been formed from, the bioplasm. Like other kinds of formed material, it possesses no power of absorbing nutritive pabulum, nor can it convert this into tissue like itself. All additions to its substance take place at those points only at which bioplasm exists.

163. Bioplasts of white fibrous tissue.—The little masses of bioplasm situated at regular distances throughout the tissue, and having the appearance of nuclei, are the only parts engaged in the process of growth, and upon the outer part of each is a layer of soft formed matter not yet converted into the firm unyielding fibrous tissue. From each there extends, for some distance amongst the fully formed tissue, threads of imperfectly developed formed material which resists the action of acetic acid and refracts highly—circumstances which have led to the opinion that from each nucleus, fibres of *yellow elastic tissue* were prolonged, and, as a consequence, it was supposed that the "nuclei" and their supposed "fibres," or nuclear fibres which were embedded in the white fibrous tissue, had nothing to do with its formation. The former were supposed to represent *cells*, and the latter an *intercellular substance*. Subsequently, Virchow included them in his catalogue of juice-conveying channels. Careful examination of properly prepared specimens of the same kind of fibrous tissue at different ages will, however, convince any careful observer that the theories now taught are untenable, and that the facts may be satisfactorily explained upon the more simple view of the structure

and formation of fibrous tissue I have ventured to bring forward. See my Lectures delivered at the Royal College of Physicians, 1861.

164. Repair of white fibrous tissue.—This simple tissue is repaired after injury by the development of tissue of the same character. White fibrous tissue may be formed by white blood-corpuscles, or by the masses of bioplasm descended from them. In the repair of injuries to arteries and veins, Mr. Lee and myself traced the production of white fibrous tissue in what was clearly at first but fibrin deposited from the blood, and I have shown that the recent lymph in certain inflammations has a similar origin, and is formed in the same way. In the repair of a divided tendon, masses of bioplasm probably result partly from the multiplication of the adjacent bioplasm of the tissue itself, and partly from the white blood-corpuscles which have escaped from the divided vessels, or from masses of bioplasm descended from these.

165. Bioplasm of the cornea.—Stellate masses of bioplasm are remarkably distinct in the corneal tissue of all animals, where they exist in great number, and possess long branching processes which anastomose freely with one another, and which may be distended with fluid, or contain very little, as was explained in the case of the branching pigment cells of the frog, § 131. These are the so-called corneal corpuscles, and are to be demonstrated in any corneal tissue without difficulty. Amongst them are, however, masses of bioplasm which belong to the nerves, and some few which are not connected with any tissue (wandering cells of Recklinghausen). In specimens I have prepared the numerous stellate masses of bioplasm are seen very distinctly, and the anastomoses between the radiating processes can be detected without difficulty. These bear to the firm but transparent corneal tissue just the same relation as the

stellate masses of bioplasm existing in certain specimens of tendon bear to that texture. The number of these freely connected masses of bioplasm disseminated through the corneal tissue renders this texture permeable to fluids, and probably allows great alterations to take place in its internal structure, very quickly leading to considerable modifications in its thickness, and perhaps in its refractive power during life. In properly prepared specimens, the masses of bioplasm which are connected with the nerve fibres may be shown to be distinct from those of the corneal tissue, and the finest ramifications of the nerves which may be traced in the substance of the corneal tissue to have no connexion with the radiating processes of the corneal corpuscles, or with the bioplasm of these bodies. Kühne some time since published a memoir, in which he endeavoured to prove that some of the processes of the corneal corpuscles were continuous with delicate ramifications of the nerve fibres;* but although I have seen many specimens which on first sight appeared to justify such an inference, I have been convinced, on further and more careful examination, that this was not the case, and I have been able to focus the delicate nerve fibre distinct from the prolongations of the corneal corpuscles, and to prove that these bodies were situated upon different planes.

166. Yellow elastic tissue.—The bioplasm of yellow elastic tissue is so very indistinct in specimens examined in the ordinary way, that many authorities have concluded that this tissue is altogether destitute of living matter, and that its formation is not due to nuclei or cells of any kind. It is, however, obvious, that in ordinary specimens the small masses of perfectly clear, transparent, structureless bioplasm would be completely hidden by the highly refractive, firm, well-defined fibres of the elastic tissue. But no

* "Untersuchungen über das Protoplasma und die Contractilität." Leipzig, 1864.

difficulty is experienced in detecting the bioplasm of this tissue, if it is prepared according to the plan I have described. The carmine fluid tinges the bioplasm of this tissue as well as every other kind; and in properly prepared specimens oval masses of bioplasm are seen adhering to the fibres of yellow elastic tissue, and bear to it the same relation that the bioplasm of some other tissues bear to the formed material of these. The bioplasm of yellow elastic tissue is so easily demonstrated in the young ligamentum nuchæ of the lamb, in which the oval masses may be seen so distinctly and in such great numbers, that one cannot but feel astonished that any doubt should exist on the point. But in such questions conjectures and speculations have hitherto influenced both teachers and pupils more than accurate observation. By careful examination fibres may be found in various stages of development, from the thinnest and scarcely visible line to the well-known distinct cylindrical fibre. The bioplasm is seen as an oval mass upon one side of the fibre, and passing from either extremity to the surface of the fibre may be detected, with the aid of high powers, an extremely delicate tissue, which is the soft and imperfectly formed yellow elastic ligament. In the case of some of the larger fibres, I have been able to trace a gradual alteration in density of the delicate tissue just referred to, in proceeding from the mass of bioplasm towards the fibre until the firm dense texture of the actual yellow elastic tissue is reached. The new tissue thus produced contributes to the thickening of the fibre. The appearance seen in many cases is such as to justify the inference that the bioplasm moves along the surface of the fibre, leaving behind it as it goes a small proportion of soft formed material, which gradually undergoes condensation, and becomes slowly converted into yellow elastic tissue. In this way each fibre is increased in thickness. Concerning the

origin of the finest fibres of yellow elastic tissue from oval masses of bioplasm, there will not remain the slightest doubt in the mind of any one who has examined properly prepared specimens of this tissue at an early period of its development. Other forms of yellow elastic tissue from the ligamenta subflava, vocal cords, coats of arteries and veins, and from other parts, also contain masses of bioplasm, which may be demonstrated in the manner I have referred to.

167. Ligamentum nuchæ of the giraffe.—The fibres of the ligamentum nuchæ of the giraffe are very large, and remarkable for exhibiting at short intervals transverse markings, which were first noticed by Professor Quekett. These markings are situated in the internal part of the fibre, and do not usually extend quite to its outer surface. They probably depend on contraction of the oldest part of the formed material taking place as it gets dry and condensed after its formation is completed. Unfortunately, I have not had an opportunity of obtaining a portion of fresh ligamentum nuchæ of a giraffe, so that my specimens are defective in not exhibiting the bioplasm of this particular form of yellow elastic tissue.

LIST OF MICROSCOPICAL SPECIMENS ILLUSTRATING LECTURE VI.

No.		No. of diameters magnified.
37.	Simplest form of connective tissue; lamb, at a very early period of development, showing bioplasm and tissue	215
38.	Simplest form of connective tissue; human subject, at a very early period of development, showing bioplasm and tissue	215
39.	Tendon at birth, showing rows of oval masses of bioplasm very near to one another	215
40.	Tendon; old man, age 74, showing rows of oval masses of bioplasm, separated from one another by much tissue	215
41.	Tendon; kitten at birth, and adult cat	215

No.		No. of diameters magnified.
42.	Yellow fibrous tissue, showing oval masses of bioplasm	215
43.	Yellow fibrous tissue; lig. nuchæ giraffe, showing transverse markings	215
44.	Junction of fibrous tissue and cartilage, frog; showing bioplasm of both tissues	215
45.	Fibrous tissue of the cornea, rabbit; showing stellate masses of bioplasm which anastomose with one another in many situations	215
46.	Bioplasm of growing fibrous tissue; green tree frog	215

LECTURE VII.

Cartilage—Of "Cells" and "Intercellular Substance"—Formation of Clusters of Bioplasts—Outline of the "Cartilage Cells"—Changes in the Matrix after its formation—Junction between Tendon and Cartilage—Of the formation of Septa or Partitions between the Bioplasts—Division of Bioplasm of Cartilage—Question of "Cell-wall," "Cell Contents," &c., in Cartilage—Perichondrium—"Cellular" Cartilage from Mouse's Ear—Spongy Cartilages—Fibro-Cartilage—Changes in Bioplasm of fully-formed Cartilage—Changes in Disease—Adipose Tissue—Fatty Matter—Formation of Adipose Tissue—Bioplasm of the Fat Vesicle—Fatty Degeneration—Of the removal of Adipose Tissue, and the absorption of Fat—Abnormal development of Fat.

168. Of cells and intercellular substance.—It has, indeed, been maintained, and the doctrine is still widely taught, that the *connective tissues* form a class by themselves, and consist of cells or cell forms embedded in an *intercellular substance*. The formation of the "cells" and the production of the "intercellular substance" are supposed to be distinct operations. But it has been distinctly proved that in this, as well as in all other textures, masses of bioplasm (the so-called cells) existed before any vestige of the *intercellular substance* was to be demonstrated, and that the "intercellular substance" is formed from the bioplasm. The connective tissues include the various forms of connective and fibrous tissues, cartilage, and bone. The matrix of cartilage is, however, no more *intercellular* than the walls of epithelial cells are intercellular. The relation of the so-called cells to one

another, and to the cell wall, or intercellular substance in the two tissues respectively, will be at once understood if we call to mind the fact that each mass of bioplasm produces upon its surface the *tissue*, be it termed *matrix*, *cell wall*, or *intercellular substance*. This tissue accumulates between the several masses of bioplasm. Now, even in epithelial textures, at an early period of formation, the formed material does exist as a continuous mass, which occupies the intervals between the several masses of bioplasm, and exhibits an arrangement similar to that which is met with in adult cartilage and fibrous tissue; but as the growth of the epithelium advances, the portion of formed material belonging to each mass separates from its neighbours, and thus "cells" of epithelium result. I have figured a good specimen of this in "Protoplasm." See also the second part of the "Physiological Anatomy." The main difference, therefore, between adult cartilage and fully formed epithelium is at once perceived, for in the cartilage each "cell" is not marked off from its neighbours, but is represented by a mass of bioplasm, including a proportion of the so-called matrix, or intercellular substance around it, while in epithelium each separate bioplast is invested with its layer or capsule of formed matrix. Some forms of cartilage are, however, really composed of "cells," which may be separated from one another just as in epithelium. The distinction, therefore, which has been drawn between different tissues, based upon the presence or absence of "cells" in the fully-formed texture, cannot be sustained, and the classification as epithelial and connective tissues breaks down.

169. Cartilage.—I propose now to refer to *cartilage*, a tissue which possesses many points of interest, and which has formed the subject of many an anatomical controversy. It is generally stated that cartilage is composed of "*cells*" and "*intercellular substance*," and that the latter is formed and deposited in the intervals be-

tween the former, the cells being embedded in the so-called intercellular substance as bricks are embedded in mortar. (§ 111.) No one, however, who has examined cartilage at the different periods of development can accept this doctrine, for he will find that, in its embryo condition, cartilage, like other tissues, consists only of spherical masses of bioplasm, around each of which is the merest trace of soft and delicate formed material. The bioplasm is in direct continuity with the formed material of the matrix, and in some forms of cartilage from the frog the passage of the living formless matter into the formed material can be most positively demonstrated. As the cartilage advances in development it will be found that the formed material between the masses of bioplasm increases in proportion, so that if several specimens of the same kind of cartilage be taken from the same part of the body of the same species of animal at different ages, and examined, it will be found that the proportion of bioplasm corresponding to a given bulk of cartilaginous tissue gradually diminishes as the tissue advances in age. In specimens of the sternal cartilage of the kitten at birth, of the cat at six weeks and at three months old, and of the full-grown animal which have been prepared, the facts just referred to are clearly demonstrated. The equable increase of the cartilaginous tissue in all directions is effected, and the expansion of the whole, without folding, crumpling, contraction, or stretching of any part, is beautifully provided for.

170. Formation of clusters of bioplasts in cartilage.—In those specimens of cartilage in which each individual mass of bioplasm divides so as to produce clusters of four or more, and these again divide to produce secondary or tertiary clusters, it will be found that the quantity of formed material between the primary clusters is greater than that between the secondary and tertiary clusters, a fact which receives

ready explanation upon the view of the formation of cartilage which I have taught. As growth proceeds, the deposition of cartilaginous tissue takes place more slowly, while, by the condensation of that which has been already formed, room for the addition of new tissue is obtained. As the cartilage approaches its fully formed state, the tension resulting from the deposition of new tissue containing much fluid immediately around the bioplasm gives rise to a slight difference in refraction of the formed material in this situation, and it appears glistening and more translucent than the tissue generally.

171. "Outline" of the cartilage "cell."—It not unfrequently happens that, in adult cartilage, the bioplasm becomes detached from the formed material, and appears as a spherical or oval body with a dark outline, lying in a cavity (vacuole or closed space) in the so-called matrix of the cartilage. The surface of the mass of bioplasm may afterwards become further condensed, and thus results the appearance which has led many to the conclusion that a true cell wall or cell membrane encloses the remains of the bioplasm of the cartilage. The examination of old cartilage in which these changes have occurred has led many observers to infer that complete "cells" occupied spaces scooped out in the matrix, while others thought that these cells were first formed, and the matrix deposited from the blood in the intervals between them independent of any cell action whatever.

172. Changes in matrix after its formation.—After cartilage tissue has been formed it often undergoes a certain amount of change. A fibrous appearance sometimes arises in that part of the matrix which was first formed. This probably depends upon contraction taking place in the oldest part of the formed material, but in certain forms of cartilage fibres are developed from distinct masses of bioplasm lying in the interspaces between those which are termed the

cartilage cells. These masses of bioplasm are often so very small that their presence has been entirely overlooked. Certain forms of cartilage are prone to undergo other changes after their formation is complete. Among the most important of these is the deposition of granules of calcareous matter in the substance of the matrix. § 208.

173. Junction between cartilage and tendon.—Wherever different tissues are connected with one another, the formed material of the one passes by continuity of structure into that of the other. This point is well seen in the case of cartilage and tendon. The fibrous tissue of the tendon gradually shades into the apparently homogeneous matrix of the cartilage. In some of my specimens striped muscle is seen to pass into the tendon, and the latter into cartilage, by continuity of tissue. In each of these three textures we observe masses of bioplasm bearing precisely the same general relation to the formed material of the respective tissues, although these differ from one another so very much in physical properties, chemical composition, structure, and action.

174. Of the formation of the septa or partitions between the bioplasts.—The formation of the so-called septa between the cells or masses of bioplasm has been explained in different ways. Instead of the bioplasm being considered as the active, growing, living, part of the cartilage, it has been supposed that the formed material *extends itself inwards* into it, and divides this living, growing substance into two or more parts; but it need scarcely be said that matrix, like other kinds of formed material, is perfectly passive: it may be added to, but it has no faculty of formation, nor can it move. Virchow says that the capsule of the cartilage cell *sends in septa*, "which serve as new envelopes for the young cells, yet in such a way, that even the gigantic groups of cells, which proceed from each of the original cells, are

still enclosed in the greatly enlarged parent capsules." Against this theory, I have endeavoured to prove that the matrix or intercellular substance with the membranous capsules of the cartilage cells is perfectly passive, and possesses no such capacity of extending itself. Like the cell-wall of a spore of mildew, to which it corresponds, it does not possess either moving or formative power. It *has been* produced; it has been formed; but it cannot *form*. It may be added to, but it cannot increase or build itself up out of pabulum. It may be moved, but it cannot move of itself. The outer capsule of the mildew, never possesses inherent powers of growth. It is the bioplasm which is alone concerned in the growth of the plant. § 94. So also in cartilage, the matrix is passive. The bioplasm only possesses active power. The septa do not *extend themselves in, or grow in*, but the material of which they are composed results from an alteration taking place upon the surface, that is in the oldest part of the bioplasm. In the same manner, the bioplasm when enclosed may divide, and produce formed material on its surface. It is in this way that the appearance of secondary and tertiary septa results.

175. The Bioplasm can be seen in process of division.—It is very surprising that Virchow's view should still be entertained, because any one can so easily demonstrate that the bioplasm always exists before the formed material is produced, and that the latter is never found without the former having been present. In a specimen I possess (Prep. 12, Lect. IV, p. 62), some masses of bioplasm are actually seen in process of dividing. They have been stained with carmine, and have been preserved while they were undergoing the change in question. In one there is a deep fissure, but in a neighbouring mass there is a mere indentation on one side, indicating the spot at which the division is about to occur. Any one who

examines these specimens will, I think, feel satisfied that the process does not differ essentially from the change which occurs in the amœba and the mucus corpuscle when these masses of bioplasm undergo division; while I am quite sure no one would maintain that the appearance results from the ingrowing of the matrix or formed material of the cartilage.

176. Question of cell-wall and cell-contents.—It is certain that the matrix of cartilage is never produced without the masses of bioplasm, nor can it increase, except by their agency. In disease change is observed in the rate of growth of the bioplasts. After the matrix has been produced many of the bioplasts die and disappear, but in growing cartilage they are invariably present. In recent growing cartilage there is no appearance of a cell-wall distinct from the matrix, as some maintain, nor is there an interval between the living matter and the matrix, unless post-mortem changes have occurred. The first, in fact, passes uninterruptedly into the last. The ragged outline of many of the masses of bioplasm observed in the case of the cartilage from the frog shows that the terms "cell" "nucleus," "cell contents," or "granular corpuscle," are totally inapplicable. It is clear that around such masses there can be no cell-wall. The bioplasm gradually *becomes* the matrix, and all matrix was once in the state of bioplasm. Without bioplasm there *can* be no cell-wall or intercellular substance. In this, as in other cases, pabulum is converted into bioplasm by pre-existing bioplasm, and this last is at length converted into formed material, be it fluid or solid, cell-wall, secondary deposit, or intercellular substance.

We shall find, when we come to consider the structure of bone, that the first deposition of calcareous particles takes place in the formed material at a point midway between the masses of bioplasm—that is, in *the oldest portion* of the formed material. The

deposition of the calcareous matter can be explained by physics, and can be imitated out of the body, but the matrix which is formed cannot be produced artificially. This last results from changes which occurred while the matter of which it consists was in the state of living matter, or bioplasm.

177. Perichondrium of cartilage.—The external limitary structure of membraniform cartilage called *perichondrium* is distinctly fibrous, with elongated masses of bioplasm here and there which were concerned in its formation. Beneath the perichondrium are larger masses of bioplasm, which assume more and more the character of those belonging to cartilage as we recede from the surface. It is immediately beneath the perichondrium in growing cartilage that the chief multiplication of the masses of bioplasm takes place, and masses which at one time belong to the perichondrium, at a later period are surrounded by the cartilage tissue which they have gradually produced. Near the surface of the perichondrium the vessels and nerves are distributed. It is only when cartilage is very thick that vessels are found distributed in its substance.

177.* Cellular cartilage from the Mouse's ear.—Some forms of cartilage are said to be destitute of matrix or intercellular substance, and to consist of "cells" only. The thin part of the ear of a young white mouse will afford a good example of what has been termed *purely cellular cartilage.* Very young cells or elementary parts may be seen in the course of formation. The bioplasm of these is very distinct, and lies upon the surface of the formed material, which is seen as a vesicle of delicate transparent tissue. This form of cartilage is formed somewhat differently from ordinary cartilaginous tissue, for the formed material corresponding to each mass of bioplasm is distinct from that of adjacent masses. Instead of expanding uniformly in all directions as it

grows, it forms a thin lamina which increases quickly in extent by the formation of new cells at its free edges. Its increase in thickness is very slight in comparison with its increase in extent, and takes place very slowly.

178. Spongy cartilages.—In the *spongy cartilages*, as, for example, the epiglottis and some of the other cartilages about the vocal apparatus, are many fibres which possess the reaction of yellow elastic tissue. Of these many are very fine, and so arranged as to form the boundaries of oval spaces, in each of which a mass of bioplasm is lodged. This is often angular, and from the angles delicate fibres may be traced, which are at length lost amongst the plexuses of those which form the tissue itself. It is probable that these masses of bioplasm slowly move round the cavity, and form the delicate interlacing fibres which accumulate, and constitute the elastic walls of the oval and circular spaces characteristic of this form of tissue.

Few who have not examined specimens prepared according to the method I have described will, I fear, accept the view of the structure and formation of the tissue here given. It is strongly opposed to the doctrines generally taught, which have been arrived at from studying sections immersed in water, serum, or other limpid fluid, in which however it is not possible to discern the real arrangement of the elements of the texture.

179. Fibro-cartilage.—Although this tissue, in its fully developed state, differs remarkably in structure and properties both from fibrous tissue and cartilage, at an early period of development some forms of it could not be distinguished from embryonic cartilage. The fibro-cartilage of the vertebral discs, at an early period of formation, approximates very closely to certain forms of fibrous tissue. In all cases bioplasm takes part in the formation of the fibrous-like

tissue and the transparent cartilaginous matrix. The former does not result from the latter, nor are the two kinds of tissue produced by the "differentiation" of an originally homogeneous plasma, as some have supposed, nor is the fibrous tissue the consequence of a process of "fibrillation" occurring in a previously transparent cartilage matrix. If this complex tissue be studied at different periods of development in specimens prepared according to the method I have described, it will be found that the mode of its formation differs in no essential particulars from that which obtains in the case of many other textures which we have already considered. *Why* some of the masses of bioplasm produce the peculiar substance we know as cartilage, and others give rise to that called fibrous tissue, is a question which cannot be satisfactorily answered. We are equally incompetent to tell *why* some masses of bioplasm form *muscle*, others *nerve*, others *epithelium*, and so forth.

180. General considerations with reference to the formation of tissue.—It is very important to ascertain if the different kinds of tissues are formed according to one general principle, or if the processes which lead to the production of tissues differing much in structure, composition, and function, are essentially different in their nature. There is good reason for thinking that the conditions present exert a certain influence upon the formative process, because the formed material resulting varies to some extent if the conditions under which its production takes place be modified. But, on the other hand, it is quite certain that no conceivable alteration in external conditions will cause the bioplasm which was to produce muscle to give rise to nerve, cartilage, or elastic tissue. And yet each of these kinds of bioplasm, instead of producing its characteristic formed material, might, if the conditions were modified, form connective tissue

instead. Altered conditions may cause a given kind of bioplasm, which, under favourable circumstances, would form a high tissue of a special kind, with peculiar properties, to produce a low, simple kind of connective tissue; but under no circumstances do altered external conditions determine the production of a texture higher than that which the bioplasm was destined to produce originally. The formative powers of bioplasm will readily deteriorate or retrograde, but will never advance under the influence of altered external circumstances.

181. Changes occurring in the bioplasm of fully formed cartilage.—The formation of matrix or tissue continues even in adult cartilage. Although the entire mass may undergo no alteration in size, new tissue is produced to compensate for the shrinking and condensation, which the tissue undergoes as it advances in age. Slowly indeed are these changes carried on, because the "matrix" is very slightly permeable to fluids. But the bioplasm still has the *power* to grow rapidly, and it will do so if the matrix becomes more permeable, or if the access of the pabulum to the bioplasm is facilitated by artificial means. As in other cases the rapidity of the growth of bioplasm simply depends upon the supply of pabulum. Let a thread be passed through a healthy cartilage, so as to make artificially a channel by which the pabulum may reach the bioplasts more quickly, and the operation will be very soon followed by their increase in size, division, and multiplication. The formed material in their immediate neighbourhood will be softened and otherwise altered.

Fatty matter is very often deposited by the bioplasm of cartilage. In some cases, the cavity in the matrix of the cartilage seems to be entirely occupied by the oil globule or globules. In the cartilage of the ear of some of the smaller animals which are fat and well fed, the so-called cartilage cells appear to be

occupied by globules of fat as large as those which are enclosed in the fat vesicle. The process can hardly be regarded as morbid, unless the formation of adipose tissue itself is looked upon as pathological. In this as in many other cases, it is impossible to draw a line between physiological and pathological changes.

182. In disease the bioplasm of cartilage, being supplied with an undue proportion of pabulum, increases. The formed material becomes softened owing to the altered characters and increased proportion of fluid which traverses it. The bioplasm may even appropriate the formed material itself, as we found happened in the case of the formed material of mildew, epithelium, and other kinds of this substance. The increased access of pabulum continuing, the masses of bioplasm may at last multiply to such an extent as to form a very soft pulpy texture quite unlike cartilage, or they may divide and subdivide with still greater rapidity, so as to produce pus. These changes are not explained by what is called "*irritation*," nor are the cells "*stimulated*" to take up more nutrient matter within a given period of time than in the normal state, but the alteration depends simply upon the restrictions to the access of the pabulum to the bioplasm having been to some extent removed.

Adipose Tissue.

It will be convenient in this place to refer briefly to the structure and mode of formation of a tissue which differs much from any of those already considered. Adipose tissue is made up of capillaries and cells or vesicles containing fatty matter and the bioplasm by which both the walls of the vesicle and the fat itself were formed. This adipose tissue is generally found associated with the areolar or connective tissue; but, constituting the medulla of bones, as will be described

in the next lecture, we find adipose tissue with a mere trace of connective tissue.

183. States in which fatty matter exists in the body.—But before I describe the characters of the fat *tissue*, it is desirable to refer briefly to the different forms or states in which fatty or oily substances are found; for fat exists in the body of man and in the higher animals in several different states.

In the first place, there is scarcely a fluid or tissue in the organism of any animal from which more or less fat cannot be extracted by careful analysis. *Secondly*, every form of bioplasm yields a minute quantity of fatty matter. *Thirdly*, in many parts of the body, little particles (globules and granules) of actual fat can be seen by the microscope. Such globules are present in immense numbers in every kind of milk. They are to be detected in the epithelial cells of the sebaceous glands. Oil globules are embedded in the mucus of the air passages, and are to be detected in the liver cells of all animals, while in some cases the liver cells seem to consist almost entirely of fat. In disease every tissue in the organism may be the seat of deposition of globules of fatty matter. But, *lastly*, fatty matter, and of a particular kind, is formed by special bioplasm. It forms the chief constituent of a most important tissue, *adipose tissue*, which accumulates in many parts, filling up interstices between the muscles and forming, at least in the infant, a tolerably even layer beneath the skin of the body. This layer of subcutaneous adipose tissue varies however in thickness in different parts and at different ages. In some few situations particularly where the skin is very movable over the tissues beneath, as the skin of the eyelids, there is no adipose tissue at all; or, in other words, the areolar or connective tissue in the meshes of which the adipose tissue is usually contained, is in this and some other situations, destitute of that

tissue. Fat is a bad conductor of heat, and many animals much exposed to arctic cold are remarkable for the very large quantity of adipose tissue which serves as a protective covering. In hybernating animals large quantities of adipose tissue are found just prior to the commencement of the winter sleep. The fatty matter during hybernation is slowly taken up by bioplasm and gradually changed, being probably at last got rid of as carbonic acid and water. By the slow oxidation that takes place, the slight amount of animal heat required during this period of total inactivity is developed.

184. Development of heat by oxidation of fat.— It is generally supposed that the development of heat is occasioned entirely by the disintegration of fat, the oxygen uniting with the carbon, and a proportionate quantity of carbonic acid being thus formed. But it may be fairly questioned whether the high temperature of the warm-blooded animals can be attributed solely to the combustion of fatty material, seeing that in many conditions in which the temperature rises many degrees above the normal standard within a very short period of time, the oxidising process is completely at fault, and the quanity of oxygen consumed is actually less than in health. The large amount of fat existing in every form of nerve tissue clearly indicates that the action of the nervous system so essential to the maintenance of life is in some way dependent upon the due supply of a sufficient quantity of nutrient material containing the elements from which fat may be formed, and there can be no doubt that of the fatty matter taken in the food a considerable proportion is appropriated by the bioplasm of the nerve textures.

185. The formation of adipose tissue.—The process of formation of adipose tissue may be well studied in the embryo of any vertebrate animal. Long before fat is actually produced, the embryonic matter (bio-

plasm) which is to take part in its formation can be distinguished from that which is to give rise to other textures. The several stages through which adipose tissue passes in its development may be as clearly made out in any young mammal at the time of its birth as during the earlier periods of its development. Nay, in certain cases it may be studied in an embryonic condition even in the adult. Excellent specimens which illustrate every stage of the process may be obtained easily from the areolar tissue under the skin of some parts of the body of the fully formed frog.

186. Of the distribution of blood to adipose tissue.—A tissue which undergoes great alterations in volume so quickly as this, ought to have a very intimate relationship to the blood from which it derives the elements entering into its composition. This is, indeed, the case, for adipose tissue is very largely supplied with blood, and in corpulent persons who make fat fast, the greater part of the blood of the body is probably distributed to the adipose tissue, and other tissues and organs may even suffer in nutrition. The muscles may become weak, and waste, and the nerves be impaired, owing to the nutrient material of the blood being unduly appropriated by the bioplasm of the adipose tissue.

187. Vessels.—Arteries, capillaries, and veins, are developed *pari passu* with adipose tissue. And there is not an instance among vertebrate animals of the occurrence of adipose tissue destitute of vessels. The vascularity of the medulla or marrow of bones is remarkable. The rate at which adipose tissue grows, in certain cases, is very striking, and probably the animal in which it is produced most quickly is the well bred young pig, whose adipose tissue doubles in weight in the course of a very few weeks. In the meshes of the capillary network of very young adipose tissue may be seen the little masses of bioplasm, which

are concerned in the production of fat. These are, indeed, at a very early period in contact with the external surface of the vascular wall. It certainly is not possible to determine by any appearance manifested by the numerous bioplasts in the immediate neighbourhood of the vessels, which of them are to take part in the development of new capillaries, and which are to become connective tissue or fat. The capillaries themselves multiply as the adipose vesicles grow, and the vascular network increases as in other situations, by the extension of bioplasts in a loop-like form from the capillaries already existing.

188. Of the changes in a single fat vesicle.—The changes taking place in the development of an individual *adipose vesicle* may be thus described. At first all that is to be discerned is the small oval or spherical mass of bioplasm or living matter, which is perfectly naked, that is, it is entirely destitute of a cell wall. This little bioplast usually exhibits one or more new centres of development (nuclei) embedded in it. The formation of the fatty matter occurs in this way:—in the very substance of the bioplasm, but always outside and away from the new centre or nucleus, a little oil globule makes its appearace. It results from changes in the living matter itself. A portion of the bioplasm dies, and among the substances resulting from its death is fatty matter, which being insoluble remains, while the soluble substances which are also formed, are carried away in the blood. Starch globules and other secondary deposits formed in the interior of elementary parts are produced in the same manner by the death of the bioplasm (§§ 127, 128). The fatty matter does not come from the blood as fat, and deposit itself in the cell, nor is it formed by the collection and aggregation of excessively minute granules, which traverse the vascular walls suspended in serum, as some have taught; nor is it precipitated from the nutrient fluid after the manner of crystals. But it

invariably results from the *transformation of living matter. Different kinds of living matter, as is well known, produce different kinds of fat.* The properties and composition of fat in different animals differ, because the powers of the bioplasm or living matter of each animal are so different.

189. Relation of the fat to the bioplasm.—In my lectures at the College of Physicians, in 1861, I showed the precise relation which the oil or fat bears to the included nucleus or mass of bioplasm, and I pointed out that the fat of the fat cell and the starch of the starch cell were formed by the bioplasm itself (§§ 127, 128). Nevertheless, some who have written since have affirmed that we still remain completely ignorant of the relation between the fatty matter and the bioplasm of the cell. By aid of the plan of preparation already referred to, the change in amount of the bioplasm and its relation to the formed fatty matter may be so accurately demonstrated in cells at different stages of development that it seems to me not a doubt remains concerning the mode of formation of the fat, and the true relation which the bioplasm bears in all cases to this substance.

190. Of the oil globule of the fat vesicle.—The little globule of fat having been once formed in the substance of the bioplasm, may increase in size by the addition of new particles to it, until the globule becomes larger and larger, being at last, perhaps, fifty times the size of the bioplast that remains, or the number of globules may increase until a compound mass, consisting of hundreds of separate little oil globules, results. In most mammalia, and in man, the globule is single, but in some of the reptiles (lizard, snake, chameleon) the fat cells in many of the tissues consist of numerous separate oil globules, almost uniform in size. And in some parts of the organism of some mammalia (rat, mouse), and even in certain cases in man himself, the same fact has been noticed.

In insects the "fat cells" are often of enormous size, consisting of aggregations of very small oil globules, which collect around the mass of bioplasm that has taken part in their production. In the livers of many fishes, particularly the eel, a somewhat similar arrangement may be observed. In these cases the nutrient matter passes in the interstices between the already formed oil globules to the bioplasm in the centre. The circumferential portions of the latter die, and undergo transformation into fatty matter which is deposited within that already produced. The globules on the outside of the cell or those on its surface are therefore the oldest.

191. Formation of the cell wall of the adipose vesicle.—At the same time that the oil globule deposited in the bioplasm of the developing adipose tissue increases, a change of another kind is taking place upon the surface of the mass. The living matter in this situation dies and becomes changed, so as to form a delicate *transparent structureless membrane*, which increases in extent as its contents become augmented by the absorption of nutrient material into the included bioplasm. The so-called *wall* of the adipose vesicle is therefore formed in accordance with the mode of production of formed material generally. But the wall of the adipose vesicle is of excessive tenuity, and readily permeable to fluid in both directions, so as to allow for the very free passage of nutrient material to the bioplasm in the interior, and that of fluid resulting from the changes of the bioplasm in the opposite direction towards the blood. In this way the rapid increase and removal of adipose material is rendered possible.

192. Is adipose tissue only altered connective tissue?—Some observers, consider that the adipose tissue is not a distinct texture at all, but hold that the fat cell is invariably developed from the corpuscles of connective tissue—a view which is certainly

erroneous, for, in many cases, at an early period of development, collections of bioplasts can be detected without difficulty, in relation with which not a trace of connective tissue can be found. Around the vessels of the mesentery of young animals the bodies in question are seen as well as the corpuscles of the connective tissue of the mesentery, but quite distinct from them. While, therefore, it is certain that the bioplast of the connective tissue corpuscle, of cartilage, and of some other elementary parts, may be transformed into fat cells, it is also an unquestionable fact that, in the development of adipose tissue, special bioplasts are concerned which are quite distinct from those engaged in the formation of connective tissue. The bioplasm of cartilage in highly fed animals often produces oil globules which accumulate in the so-called cartilage cell, and the bioplasm becomes pushed on one side, and so compressed that it may entirely escape notice. § 181. In the young mouse such a change is commonly observed, and not unfrequently, the fat accumulates to such an extent that the tissue might almost be described as adipose tissue, in which the ordinary vesicle or cell wall is replaced by firm cartilaginous texture. Each spherical capsule of cartilage tissue is occupied by a large oil globule, between which and the inner wall of the capsule the remains of the bioplasm that has taken part in the formation of both fat and cartilage may be distinctly seen if the specimen has been properly prepared by previous soaking in carmine fluid, § 68.

193. Fatty degeneration.—That condition which is termed fatty degeneration of the liver, and which is very common in consumptive patients, also affords a good illustration of the changes which occur when fat is formed. To such an extent does the change sometimes proceed, that a section of the fatty liver could not be distinguished from certain forms of adipose tissue. Not a particle of biliary colouring

matter or other evidence by which the real nature of the tissue may be identified remains. In some adult fishes this is the ordinary condition of the hepatic organ, and without great care in the preparation of specimens, not a vestige of hepatic tissue will be discovered. In all these instances, however, the stages through which the gland-elementary part passes may be studied without difficulty, and specimens may be obtained which show every degree of alteration, from a transparent elementary part, completely destitute of fatty matter, to a body which appears to consist only of a huge oil-globule. It is surprising how large an accumulation of fat may occur in the liver in some of these cases. As much as 66·19 per cent. was found by me in one case, recorded by Dr. Budd.*

194. Of the removal of adipose tissue and the absorption of fat.—Not less interesting than the consideration of the mode of development of adipose tissue is the question concerning the manner in which its removal is effected. It is well known that large quantities of fat which have been stored up in the body and have been collecting for a considerable time, may quickly disappear, in consequence of the fat being absorbed, and its elements applied to assist in the nutrition of tissues whose waste could not occur without consequences very damaging to the organism, and in maintaining the requisite temperature. The adipose tissue may, indeed, be regarded as a sort of storehouse, in which fat is accumulated as long as the body is abundantly supplied with food, from which it may be removed and appropriated, should a period of scarcity occur. In the winter, when the fat of the fat bodies of the frog are being absorbed, the bioplasm of each vesicle can be seen spreading around the fatty matter, which gradually

* "Diseases of the Liver," 2nd ed., p. 284.

diminishes in amount in consequence of its conversion into bioplasm. On the distal side of the vesicle, phenomena of another kind are proceeding. The bioplasm is there undergoing change, and becoming resolved into substances, which are immediately taken up by the bioplasm of the blood and blood-vessels. As has been already described §§ 25 to 32, all nutritive operations are conducted through the intervention of bioplasm alone.

195. Importance of bioplasm in effecting changes.—As fatty matter is formed from bioplasm, so its removal is effected only through the instrumentality of this living matter. It cannot be removed until it has been again taken up and converted into bioplasm. Moreover, the same bioplasm is instrumental in both operations. In the one case taking certain constituents *from* the blood, increasing at their expense, and then undergoing conversion into fatty and other matters. In the other, growing at the expense of this fatty matter already produced, and becoming resolved into substances which find their way back again into the blood, and which are at length appropriated in part by other forms of bioplasm of the body. This view has been recently confirmed by Czajewicz, in some observations upon the adipose tissue of rabbits. (Reichert and Du Bois Reymond's Archiv., 1866, p. 289.) In animals which have become rapidly emaciated, the fat cells of the adipose tissue are seen to be shrunken, and, instead of containing fatty matter, fluid, with some granules and one or two oil globules, are alone found. This interesting fact was first observed by Kölliker. The amount of fat in an individual vesicle may vary from time to time;—the processes of formation, and the disintegration of the fat which has been already formed, alternating with one another.

196. Abnormal development of adipose tissue.—The uniform development of adipose tissue is some-

times disturbed, and in consequence of a circumscribed redundant growth, a tumour of enormous size may result. It is not uncommon to find this unusual growth springing from the subcutaneous adipose tissue of the limbs or trunk. In one particular spot the circumstances which determine the regular and even growth of the tissue are somehow altered, and growth having once burst its ordinary bounds, continues unceasingly, and often at an increasing rate, until a *tumour* of large size results. The structure of simple fatty tumours exactly accords with that of normal adipose tissue, and the arrangement of the capillary vessels is precisely the same. It is possible that the formation of these tumours may be due to the circumstance of a collection of bioplasm which would, under ordinary conditions, form a lobule of ordinary adipose tissue, being displaced at an early period of its development. Such a mass of developmental bioplasm being subjected to the influence of new conditions, might at a later period grow very quickly, and become the germ of one of these, often huge, morbid growths. Not only is the constantly growing fatty tumour like adipose tissue in its general characters, but in many instances the minute structure of the morbid growth could not be distinguished from that of the normal tissue.

MICROSCOPICAL SPECIMENS ILLUSTRATING LECTURE VII.

No.		No. of diameters magnified.
47.	Cartilage, mouse's ear; showing bioplasm and cartilage	215
48.	Cartilage, rib; very young lamb: showing multiplication of bioplasm near surface..	215
49.	Cartilage, rib of kitten one day old, and of adult cat; showing different proportions of bioplasm and formed material	215
50.	Articular cartilage and subjacent bone, human finger	130
51.	Fibro-cartilage, intervertebral discs; kitten, one day old	215

No.		No. of diameters magnified.
52.	Bioplasm of spongy elastic cartilage; epiglottis ..	215
53.	Developing adipose tissue with vessels injected. A fat vesicle with its bioplasm is situated in each vascular space	130
54.	Adipose tissue, showing nuclei of fat vesicles. A vein crosses the centre of the field, to the left of which is a bundle of nerve fibres	40
55.	Fat cells in different stages of development; frog	215
56.	Young cells of potato; showing bioplasm and very small starch granules which have commenced to form..	215
57.	Fully formed cells of potato; showing fully formed starch grains	215

LECTURE VIII.

Of Bone—Organic and Inorganic Matter of Bone—Formation of Organic Matter—Cancellated Texture and Compact Tissue—Living Bone and dead dried Bone—An elementary part of Bone—Living Bioplasm of Bone—Lacunæ and Canaliculi—Lamellæ—Perforating Fibres—Periosteum and Medullary Membrane—Formation of Osseous Tissue—Bioplasm of the Lacunæ—The views of Kölliker and Virchow—Changes beneath Periosteum and Medullary Membrane—Medulla or Marrow—Marrow Cells—Changes occurring in an Haversian System of fully formed Bone—Of the disintegration and removal of Bone—Formation of primary Bone—Repair of Bone—Inflammation of Bone—Caries and Necrosis.

One of the most interesting structures in the body as regards the process of tissue-formation is bone. By studying this texture at different periods of its development we may determine what part of the process is due to *physical and chemical changes*, and what to exclusively *vital actions*.

197. Organic and inorganic matter of bone.—It is important to bear in mind that every kind of bone in its lifeless state consists of an *organic substance* which yields gelatin by boiling, and *inorganic salts* composed principally of earthy phosphates. The organic and inorganic matter, although intimately incorporated, may be separated by the action of hydrochloric acid, which dissolves the earthy and leaves the animal matter. This exactly corresponds in form and size to the original bone. If, on the other hand, the animal matter be destroyed by a red heat, the earthy material will also retain the original form of the bone,

although in consequence of having been deprived of its organic matter, it will be found to be so brittle that it may be broken down by very slight pressure.

198.—Formation of the organic matter.—The formation of the organic matter is an operation quite distinct from its impregnation with earthy material, and the first part of the process may occur without the last. The bone tissue may be *formed*, but if not impregnated with earthy salts, it will be destitute of those important physical properties for which osseous tissue is required. It will be so soft, that it will neither support the weight of the body nor constitute a firm framework for the the attachment of muscles.

199. Of the cancellated texture and compact tissue of bone.—In some situations bone tissue is arranged to form a texture exhibiting spaces or cancelli. This is called the cancellated texture of bone. When dried, cancellated tissue exhibits a number of spaces like sponge, and has been termed spongy bone. In the recent state, however, all the spaces are occupied with fatty matter, traces of connective tissue, and vessels, except in the case of birds, in which class, with some exceptions, the spaces in the bones contain air. The bony walls of these spaces are composed of thin plates or spicules of osseous tissue, on the outside of which vessels are freely distributed. If the bony walls of the cancelli become very much thickened, so as only to leave room for one vessel in the centre, we have an approach to the other kind of bone tissue which is called *compact tissue*. This, however, in its perfectly formed state, contrasts remarkably in character with the spongy cancellated texture. The compact tissue is so firm and dense that you would not suppose it was traversed by numerous vessels which run in channels (Haversian canals), and are connected here and there by transverse branches, so that if the whole of the bony

matter were removed from the compact tissue, we should have left a web or net-work of capillary vessels having longitudinal meshes.

200, Of living bone and of dried dead bone.—The authors of many manuals and treatises on minute anatomy have described the structure not of *living* or *recently dead* bone, but of bone which has been *dead for a long time and has undergone dessication.* The student is thus led to acquire a notion of the structure of bone as imperfect and incorrect as would be that which he would form of the structure of skin, nerve, or muscle, were he to examine dried specimens of these tissues only We desire to learn how tissues live and grow and decay in the living body; but the structure of bone and teeth has been described, not as it may be demonstrated in these tissues when they are fresh, but only, as it appears, after the textures have been altered by *death*, and after they have been completely deprived of their *living matter.*

201. An elementary part of dead dried bone.—An elementary part of fully-formed *dead* and *dried bone* consists of a *space* (*lacuna*), occupied in the recent state with bioplasm, and surrounded by a portion of hard osseous tissue which is traversed by numerous pores or channels (*canaliculi*) passing from one little space (*lacuna*) in a tortuous manner to adjacent lacunæ.

202. An elementary part of living bone.—An elementary part of *fully-formed living bone* consists of a mass of bioplasm surrounded on all sides by, and continuous with, a thin layer of soft formed material, which passes uninterruptedly into the hard calcified formed material (*matrix or intercellular substance of authors*). This hard material is in the fully formed bone penetrated everywhere by very fine channels (*canaliculi*) through which the nutrient material passes towards the masses of bioplasm; for, as the hard material in its fully formed state is almost impermeable, nutrient fluid could not reach the bioplasm

were it not for these little canals or pores traversing its substance.

An elementary part of every kind of bone at *a very early period of its formation*, consists of a mass of bioplasm, surrounded by a certain proportion of granular, homogeneous or more or less fibrous (?) formed material. This last becomes the seat of deposition of calcareous matter, which proceeds in a direction from *without inwards*. The formation of the canaliculi takes place in the same direction. We shall find, contrary to the generally received opinion, that the formation of these tubes commences not at a point nearest to the bioplasm, the so-called "cell," as has been repeatedly stated, but at a distance from it. § 208.

203. Living bioplasm of bone.—The difference between *dead bone* and *living bone* is simply this: in the first, *formation* of tissue has everywhere ceased; while in the last, it is still proceeding, and around each mass of bioplasm the *production* of matrix and the deposition of calcareous salts in the matrix already formed is going on. These changes may proceed very slowly, but in all living bone they occur. The only matter in a living bone which is actually *alive* is that which is ordinarily termed the "*nucleus*" or the "*bone cell*" in the space or lacuna, and which is here spoken of as the bioplasm or living matter. The fully-formed osseous tissue around, on the other hand, is to all intents and purposes, as devoid of life while the bone yet remains a part of the living body, as after it has been removed, or after the body has died. This small mass of bioplasm, perhaps not more than one-twelfth of the bulk of the proportion of bone tissue which belongs to it, alone possesses active powers. This only can *grow* and give rise to the *formation of matrix*. Bone cannot *produce bone* any more than *tendon* can give rise to *tendon*, or *muscle* form *contractile tissue*, but the

bioplasm only is instrumental in the formation of every one of these tissues, and without this the production of tissue is impossible.

204. Lacunæ and canaliculi.—Masses of bioplasm are contained in the little spaces in the bone (lacunæ), which are present in every kind of bone tissue, the distance from each lacuna to the neighbouring lacuna being seldom more than $\frac{1}{1300}$ inch. Moreover, each lacuna is connected with its neighbours by numerous minute channels (canaliculi), along which fluid readily passes from one mass of bioplasm to another. Thus every part of the hard bone tissue is irrigated with fluid, and the little channels are usually not separated from one another by a distance greater than the five-thousandth of an inch, so that no particle of osseous tissue is removed further than half this distance from the fluid which flows in the canaliculi. In the living state, these canaliculi always contain fluid, and this fluid is always in motion, flowing to and from the nearest masses of bioplasm; but if bone be dried, the bioplasm in the lacunæ shrinks, the fluid in the canaliculi disappears, and air rushes in to occupy the *spaces and canals thus formed.*

205. Lamellæ.—The bone tissue is so formed as to constitute a series of superposed thin plates called lamellæ. These are concentrically arranged round the vessel in the Haversian canal, and in section they appear as concentric lines one within the other. There are lamellæ immediately beneath the periosteum and medullary membrane, which extend uninterruptedly for a great length, or entirely round the bone. These are called respectively the *periosteal* and *medullary lamellæ.*

206. Perforating fibres. — Dr. Sharpey has described, under the name of *perforating fibres*, some peculiar processes of osseous tissue which appear to perforate the laminæ of bone and, as it were, pin them together. The mode of formation of these fibres

has not been satisfactorily explained. They are to be found by pulling asunder the sections of lamellæ of a decalcified cylindrical or cranial bone. From the circumstance that some of these fibres have escaped calcification, the organic matter has shrunk in the dried bone, and thus has resulted a *tube*, which has been referred to by Tomes and De Morgan, and other observers.

207. Periosteum and medullary membrane.—The compact external surface of bone (except where it helps to form a joint, is covered by a firm tough membrane, termed the *periosteum*, which, like the perichondrium investing cartilage, consists of white fibrous tissue, densely interwoven in all directions, § 212. The cancelli are filled with fat, or *medulla*, the marrow of bone. They are lined by a delicate membrane, called the *medullary membrane*, which serves to support the fat. In the shaft of the long bones the medulla is contained, not in ordinary cells, but in one great canal, which occupies the centre of the shaft, the *medullary canal*. Here the *medullary membrane* lines the compact tissue that forms the wall of the cavity.

Both the periosteum and the medullary membrane adhere intimately to the bone. Both are abundantly supplied with blood-vessels, which, after ramifying upon them, send numerous branches into the bone. These membranes are of great importance to the nutrition of the bone, inasmuch as they support its nutrient vessels; and, if either of them be destroyed to any great extent, the part in contact with them necessarily perishes: and they not only cover the outer and inner surfaces of the bone, but *also send processes, along with the vessels, into minute canals traversing the compact tissue*, and are, through the medium of these, rendered continuous with one another. When the periosteum or medullary membrane is torn away from the surface of a fresh bone, the vessels may be seen very readily passing from

the under surface of the membrane into the tiny channels (Haversian canals) which pass obliquely into the compact tissue. The vessels of the bone ramify throughout its substance, and if they have been injected previous to the removal of the calcareous matter by the action of acid, they will be distinctly seen ramifying through the semi-transparent animal substance. A preparation of this kind dried, and afterwards preserved in spirits of turpentine, serves beautifully to exhibit the disposition of the vessels in bone.

Formation of Osseous Tissue.

The osseous tissue itself is formed in the same way in the cancellated texture and the compact tissue, and it is worth studying very carefully. The changes may be beautifully seen in the formation of the cranial bones of the frog, which continue to grow at their edges, even in the full-grown animal. In this structure an opportunity is afforded of observing every stage of the process of bone formation in a single specimen. At the extreme edge is ordinary cartilage, which gradually passes into tissue which is being infiltrated with calcareous deposit; and, lastly, we come to the fully formed bone.

208. Conversion of cartilage into bone.—At the outer edge where the bone is growing, we may also study the development of cartilage. A little further inwards the formation of cartilaginous tissue is complete. Passing in the same direction, we soon observe that a change is taking place in the matrix. Granules and highly refracting globules have been deposited in its substance. The deposition of this material, which is easily proved to consist of calcareous salts, invariably commences in the matrix at a point equidistant from contiguous masses of bioplasm—that is, in that part of the formed material which is, of course, most distant from the bioplasm.

This is the part of the tissue which was first formed. Soon each mass of bioplasm becomes surrounded by a ring of such globules, some of which coalesce, but converging lines of matrix are always left here and there uncalcified, and these are traversed by currents of fluid holding various substances in solution, which flow to and from the masses of bioplasm. The continual flowing of the fluid prevents the precipitation of calcareous material in these channels, and, probably, gradually dissolves the matrix, so that little canals are formed at short intervals in the calcifying cartilaginous tissue. More calcareous matter is deposited nearer and still nearer to the bioplasm in the centre of the space, and at its outer part the bioplasm continues to produce more new cartilage matrix, which in its turn becomes impregnated with calcareous salts. The little canals are at the same time increasing in length, although the distance from the centre of the bioplasm to the spot in the cartilage matrix where the canal began to be formed always remains the same. As the deposition proceeds, the bioplasm becomes smaller, and the space in which it lies is gradually encroached upon until in the fully formed bone it remains as a very small mass lying in a little cavity (lacuna) which communicates with neighbouring lacunæ by the little canals (canaliculi), the formation of which has been described. This view concerning the formation of lacunæ and canaliculi is very different from that generally taught, for most authorities look upon the lacunæ as *cells*, the canaliculi as *processes from them*, and the osseous tissue as an *intercellular substance*.

209. Of the bioplasm of bone.—If the growing bone of any animal be examined, after having been properly prepared with carmine fluid, the masses of bioplasm will be demonstrated without difficulty, in the lacunal spaces. The fact of the presence of soft matter in the lacunæ of fully formed bone has how-

ever been generally admitted by anatomists since 1850. Under the name of "nucleus" the bioplasm had been observed in the lacunæ of many specimens of osseous tissue, and Tomes and De Morgan demonstrated indications of these bodies in the lacunæ of fossil bone, in their paper published in the Phil. Trans. in 1853. Subsequent investigations have proved that in every kind of growing bone, at every period of life, are numerous masses of bioplasm, without which the formation of bone tissue could not have taken place, and which are concerned in all the important changes going on in it during life. As long as the masses of bioplasm are living, the changes characteristic of living bone may take place, but if these be dead in any part of the bone this soon separates from the rest, and ceases for ever to be the seat of vital changes.

The masses of bioplasm are as necessary for the production of bone as they are for the formation of every other tissue. They are not directly concerned in the precipitation of the calcareous matter, but in their absence the production of matrix would be impossible. It is alone by the instrumentality of these masses of bioplasm that the regular circulation of fluids holding in solution the calcareous salts, is maintained throughout every period of bone formation. By this process the regularity in the formation of osseous tissue, which is so remarkable, is secured.

The deposition of the inorganic salts is no doubt due to physical and chemical change; but the precise locality of the precipitation, as well as the mode of deposition of the calcareous particles, is determined by actions (*vital*) of which the *bioplasm or living matter* is the seat.

210. Formation of lacunæ. The views of Kölliker and Virchow.—Kölliker considers that the *capsule* of the cartilage cell and the "intercellular" matrix of the temporary cartilage of developing bone become

impregnated with calcareous matter, while the "granular cell" corresponding to the primordial utricle of the vegetable cell, remains within unaltered. He thinks that the canaliculi extend through the matrix by "resorption."

Virchow says bone contains, "in an apparently altogether homogeneous basis-substance, peculiar *stellate bone cells* distributed in a very regular manner." According to this view it is maintained that the matrix is formed as a true *intercellular* substance, while from the "cells" it is supposed that processes grow out, and that these gradually make their way through the matrix and anastomose with corresponding processes from neighbouring cells. The "lacuna" is said to be occupied by a "cell" with "stellate processes" which pass into the canaliculi. Virchow expresses himself very clearly as to the manner in which the supposed processes are formed from cells:—"The cartilage cells (and the same holds good of the marrow cells) during ossification throw out processes (become jagged) in the same way that connective tissue corpuscles, which are also originally round, do, both physiologically and pathologically. These processes, which in the case of the cartilage cells are generally formed after, but in that of the marrow cells frequently before, calcification has taken place, bore their way into the intercellular substance, like *the villi of the chorion do into the mucous membrane and into the vessels of the uterus*, or like the Pacchionian granulations (glands) of pia mater of the brain into (and occasionally *through*) the calvarium." Again, "the cells which thus result from the proliferation of the periosteal corpuscles are converted into bone corpuscles exactly in the way I described when speaking of the marrow. In the neighbourhood of the surface of the bone the intercellular substance grows dense and becomes almost cartilaginous, the cells *throw out processes, become*

stellate, and at last the calcification of the intercellular substance ensues!" According to this view the canaliculi are the processes of the cell which "bore" their way through the already calcified tissue, and in some unexplained mysterious manner manage exactly to meet the processes of adjacent cells, and become continuous with them. Canaliculi, however, exist long before the formation of the calcified tissue is complete.

There are few points in minute anatomy upon which such different views have been advanced as the one under consideration, for observers differ not only in the explanations and opinions they have put forward, but there are irreconcilable differences regarding their statements of fact. To assert that the cells throw out processes is merely fanciful, for there are no facts whatever to justify such a statement. Although it has been repeatedly stated that the bone "cell" with its canalicular prolongations may be actually detached from the matrix into which its processes have bored their way, I have never been able to obtain any specimens which appear to me to justify such an inference, while I have utterly failed in every attempt to prepare specimens which would lead me to infer the existence of any grounds for such a conclusion.

With regard to Virchow's view, it may be remarked that although it is true that in certain cases in which the bioplasm is more or less stellate, the so-called *processes* project a very short distance from the mass, they *never*, as far as can be ascertained, *correspond* in number with the canaliculi which exist in the fully formed bone, the latter being twice as numerous as the processes in question. Almost any form of bioplasm may exhibit this stellate appearance, but it has nothing whatever to do with the formation of the canaliculi in bone. *That part of the canaliculus nearest to the lacuna is the last that is formed*, whereas if the

canaliculus were a process of the bioplasm, that portion nearest to the bioplasm would be the first part developed. The first part of the canaliculus which is formed is not *that which is nearest to*, but that which is *most distant from, the bioplasm*, and the widest part of the canaliculus is always that nearest to the lacuna. The lacuna of young imperfectly developed bone is, of course, always much larger that that of the fully formed osseous tissue of the same animal.

Virchow, it will be remarked ventures to say very little concerning the changes which result in the deposition of calcareous matter and offers no suggestion as to the nature of the process by which calcification is effected; nor has he determined exactly in what part of the matrix the change commences. He tells us that "at last the calcification of the intercellular substance ensues!"

211. The offshoots do not correspond to the canaliculi.—The appearances which have led Virchow and other observers to maintain that the lacunæ and canaliculi formed a cell with its offshoots, can be satisfactorily explained without resorting to such a view, which is quite incompatible with many facts which have been conclusively demonstrated, while all attempts to show the supposed offshoots *boring* their way have signally failed. The stellate appearance of the nucleus, which was supposed to indicate the commencement of the shooting-out operation, has nothing whatever to do with the formation of the canaliculi; for the "offshoots" never correspond in number with the canaliculi. Virchow, however, talks of the processes which are to become the canaliculi "boring" their way "through the intercellular substance like the villi of the chorion do into the mucous membrane, and into the vessels of the uterus"—forgetting that the canaliculi exist before the formation of the so-called "intercellular substance" is complete, and that the end of each villus of the chorion is a mass of

bioplasm, while nothing of the kind exists in the case of the canaliculi. The notion of cells shooting-out processes which meet those of other cells is a most fanciful one, and totally unsupported by observation. The idea as applied to the bone-cells is purely hypothetical, and would never have been advanced had it not been first assumed that the lacuna with its canaliculi was a stellate cell. Such an assumption necessarily required new assumptions to support it, and so the unfortunate hypothesis of "boring processes" had to be invented.

212. Of the changes beneath the periosteum and medullary membrane.—The outer layers of the periosteum exhibit a simply fibrous structure, but its deeper portion, which is continuous with the bone tissue, has a totally different anatomical arrangement. Here are seen a number of elementary parts of unossified bone tissue, each consisting of an oval mass of bioplasm invested by a soft formed material. The deeper layer of the periosteum of a young animal is the seat of the formation not only of new bone but of complete Haversian systems. The elementary parts multiply, and the capillary vessels are gradually enclosed by the growth of tissue, which at length undergoes ossification. This process has been fully described by Messrs. Tomes and De Morgan.

213. Transplantation of periosteum.—It has been shown by M. Ollier, of Lyons,* that if portions of the periosteum be transplanted to various parts of the organism, bony tissue will be formed in the new situation. This process is due to the growth and development of the masses of bioplasm which exist in such great number at the deep surface of the fibrous periosteum. These grow and multiply, and produce formed material, just as if they had remained in the original seat of their development—a striking

* "Journal de la Physiologie," tom. ii., pp. 1 and 169.

proof that the *kind* of tissue formed by living matter depends upon its *powers* rather than upon its position or the conditions to which it is exposed. In certain forms of bone cancer very minute portions of actively growing bioplasm are sometimes carried to the lungs, and grow and multiply and give rise to bone cancer in the pulmonary tissue, proving that the bioplasm possesses the peculiar property or *power* of forming this particular tissue if supplied with pabulum.

214. Of the medulla or marrow of bone.—The medulla of bone is a form of almost pure adipose tissue, which contains very little connective tissue, associated with it. It is a question of great interest how this adipose tissue is produced. It fills the cancelli, and exists in quantity in the medullary cavity, and is even found in large Haversian canals. There is no doubt that the elementary parts which form at length the fat cells of the marrow, are the direct descendants of the bioplasts which gave origin to those taking part in the formation of the bone. In fact the proper marrow cells (myeloid cells) may become converted into bone-tissue or into marrow. During development, as would be supposed, these "myeloid" cells contain little or no fat, but as the bone attains its permanent character, many of them become "fat cells" instead of being converted into bone-tissue. In the majority of birds these cells do not form fat, but as the bones are freely penetrated by air, the matter which would be fat under other circumstances, is probably oxidised as fast as it is produced, and eliminated as carbonic acid.

215. Of the marrow cells, or myeloid cells, and of the formation of the plates and spicules of the cancellated tissue. — The little plates or cylindrical spicules of bone which enter into the formation of the cancelli are represented at first by soft masses, consisting of bioplasts which correspond to several elementary parts of bone. These masses may often

be detached, when they are found to have the appearance of large compound cells, consisting of many smaller ones. They are met with in numbers beneath the periosteum as well as beneath the medullary membrane. These, in fact, represent the early stage of the formation of bone tissue, and ordinarily undergo ossification. In some forms of disease, however, they grow and multiply very rapidly without becoming condensed or calcified. They may accumulate so as to form a vast amount of soft and rapidly increasing spongy tissue, which has been truly considered to be closely allied to certain forms of cancer. The masses above described vary much in size and form in the healthy state, and from the circumstance of their being found in great number in close proximity with the marrow, they have been termed "myeloid cells." In no structure of this kind do we meet with anything to justify the idea that the lacunæ and canaliculi are stellate cells. Each mass is oval, and usually smooth on the surface. The so-called "myeloid cell" is therefore only a spicule or part of a lamina of bone tissue in its soft state containing numerous masses of bioplasm, with as yet very little intervening formed material, and no calcareous matter.

216. Of the changes occurring in an Haversian system of fully formed bone.—Many years ago Messrs. Tomes and De Morgan (Phil. Trans., 1853) discovered that some of the Haversian canals of the compact tissue of bone were much larger than others, and that the outline of the larger canals as seen in a thin transverse section of the compact tissue, was uneven. By further examination, these observers succeeded in ascertaining the explanation of this important fact. They demonstrated that the several adjacent Haversian rods of bone tissue varied very much in age, and that of those seen in a section, even in adult bone, some had only just been formed, or were in course of formation at the time the bone was

taken for examination, while others had existed for a considerable period. Some were already undergoing decay, and of others nothing was left. The highly important conclusion was established by these researches, that even in fully formed bone, the compact hard tissue was undergoing constant change. Old Haversian rods were continually being removed, and at the very time that adjacent ones were being formed. Thus, in a transverse section of bone, we look upon sections of Haversian rods of every age, and in every degree of change, from the young rod just being formed, to the old one of which the merest traces are to be detected.

In this way, the firmness and elasticity of bone is effectually secured, all through adult life, and until we reach old age, when bone ceases to be renewed, and consequently becomes very dry and brittle. In order to form an accurate idea of the wonderful phenomena taking place, we must consider the changes which ensue in a single Haversian system, and which make up its life history—and, that the account may be made as simple as possible, I shall ask you to imagine what would be seen actually going on in an Haversian canal if it were possible for the eye to follow the operations from their commencement to their close.

Let us then consider what we should see were it possible for us to watch the various changes which take place in a single Haversian system after it had reached its mature state, and was about to be removed and replaced by another. Just external to the vessel occupying the Haversian canal, in the slight interval between the vascular wall and the surface of the osseous tissue, we should discern a number of little bioplasts, which would be growing and multiplying. Many would be in very close contact with the bony tissue, which is to be gradually acted upon and slowly appropriated by the particles of living matter.

As more and more bone tissue disappears, an increasing space between the vessel and the bone tissue results. This space is entirely occupied by bioplasts. Indeed at this time instead of the Haversian rod we should find around its central vessel only a cylindrical column of soft material, consisting almost entirely of small living bioplasts, each about the size of a white blood corpuscle or somewhat less than this, which have grown and multiplied chiefly at the expense of the bone tissue which had been removed by them. The elements of nutrition required by the bioplasts, and which are not present in the bone, are no doubt derived from the blood which continues to flow through the vessels while these changes proceed. Thus is formed the "Haversian space" which is seen in a section of dead dry bone. The soft bioplasm contains so much water, that when a section of dry bone is examined, scarcely a trace of the multitude of eroding bioplasts, or of the vessel, can be seen. The bone tissue of the Haversian system having been removed, the process of erosion at the circumference of the space ceases, probably in consequence of the great distance by which the bioplasts near the bone tissue are now separated from the blood, whence certain elements necessary for their growth can alone be derived.

The process of disintegration gives place to a very different operation. Of the bioplasts in contact with the bone, some no doubt die and disappear. Others are however concerned in the production of soft formed material, which gradually becomes infiltrated with calcareous matter, as described in § 208, and a layer or *lamina* of new bone results. Then immediately within this a second lamina is formed in the same manner. The formation of new layers concentrically one within the other proceeds, until a new Haversian system results. The lacuna and canalculi are formed precisely as I have already described in § 208.

After this new Haversian rod has existed for a certain

time, it is removed to give place to another. While one rod is being formed, some of its neighbours are being removed. Thus the compact tissue is gradually renovated in every part of its substance and without its strength being in the slightest degree impaired, during the time changes, destructive and constructive, are proceeding in its very substance.

217. Formation of primary bone.—In the development of the bones of the skeleton of man and the higher vertebrata, *temporary cartilage* is the seat of formation of a very imperfect and soft spongy kind of osseous tissue, which serves only a temporary purpose, and is entirely removed before the more permanent form of bone is produced. In the expanded portion of the cranial bones, however, ossification does take place without the previous formation of the temporary or primary bone, as it has been called. The bone in question is not preceded by temporary cartilage, but from the earliest period consists of fibrous tissue, like the periosteum of bones generally. The fibres of this fibrous tissue become calcified, while its masses of bioplasm, or at least some of them, take part in the formation of the future lacunæ.

The more lasting or *secondary bone* of the skeleton generally is formed at the deep layer of the fibrous periosteum; and the process agrees very closely in its general characters with that which takes place in the ossification of the expanded portion of the cranial bones. Beneath the periosteum may be seen numerous large masses of bioplasm, § 212, for the most part of an oval form, which are the agents concerned in the production of the formed material of the future bone. And the changes which take place are closely analogous to those which have already been described as occurring in the formation of bone in the frog, § 208. It is, however, much more difficult to study the changes in mammalian bone, in consequence of the firmer consistence of the tissue and the difficulty

of obtaining sufficiently thin sections for examination by very high powers. Such sections are absolutely necessary for demonstrating the changes which occur here on a scale very small compared with that upon which they proceed in the cartilage of the frog.

218. The disintegration and removal of bone.—The removal of the osseous tissue is effected upon the same principle as the removal of fatty matter, § 194, and other substances which have to be gradually dissolved and taken up by the blood as soluble substances, instead of being cast off and carried away as particles of considerable size like the old cells of cuticle or of a mucous membrane. No one would, however, have been led to expect that the hard matter of bone would have been easily dissolved away and appropriated by living bioplasm; for bone is not easily dissolved, and when subjected to the action of ordinary fluids undergoes very little change. Small pieces of bone have been subjected to the action of serum and pus for long periods of time without any appreciable change being induced. Nevertheless, it has been distinctly demonstrated that the hardest tissues like the fang of the temporary tooth, may be dissolved away, and removed during life. It is remarkable that the material concerned in the process of removal should be a soft and moist semi-fluid substance which comes into very close contact with the bone and dentine. By employing the carmine-solution as I have described, § 68, the actual particles engaged in the removal of these hard tissues have been demonstrated very distinctly, and in bone tissue at different periods of age. They are little particles of bioplasm which, as they grow and multiply, take up the formed material that was produced, it may have been, by their predecessors. In the same way it has been shown that the bioplasm of mildew may grow and live upon the formed material it has already produced, § 94. The bone tissue diappears

and the materials that entered into its composition are converted into bioplasm. Of the numerous bioplasts formed, some die, the products of their death being taken up by the bioplasm of the capillaries, and that of the blood, and the elements eliminated in other states of combination in the urine and other excretions. Many of the bioplasts, however, retain the phosphate salts and other constituents which they have taken up, and these are probably subsequently employed in the formation of the new osseous tissue which takes the place of that removed.

219. Origin of the disintegrating bioplasts.—With regard to the origin of these disintegrating bioplasts I have been able to show that at least in the case of the removal of temporary bone at an early period of life, they result from the division and subdivision of the bioplasts of the original temporary cartilage, after these had been for some time enclosed in the crypts or spaces which were formed by the deposition of calcareous matter in the formed material or matrix in the intervals between the cartilage bioplasts. See "The Physiological Anatomy and Physiology of Man." New edition, Part II., p. 278.

220. Of the manner in which the removal of the bone tissue is effected.—There are few questions of greater interest than this. We have discovered the actual agents concerned in the removal of the hard matter of bone as well as the softer material of other tissues, as well as substances in solution in various fluids in the body. It has been conclusively proved that the active substance is living bioplasm. Such is the marvellous power of this living material, that there are probably few things in nature that are proof against its destroying powers. The hardest material, even flint itself, yields to the slow but sure disintegrating action of bioplasm. The most insoluble materials, as well as the most soluble are appropriated. Fatty matter is taken up by bioplasm, and almost as

quickly as albuminous and other soluble substances. But how, precisely, is the wonderful disintegrating action effected? In the case of adult bone it is probable that the first change that occurs is the softening of the bone tissue close to the vessel of the Haversian canal by imbibition. In this way the passage of nutrient material to the little bioplasts enclosed, or partly enclosed, in the incompletely formed osseous tissue is favoured. Then the little particles of bioplasm themselves grow and multiply in the space in which they lie. The walls of the space (lacuna) are eaten away and the lacuna becomes enlarged. As the hard material disappears, instead of a lacuna occupied by a single bioplast, we find a greatly enlarged space, a gigantic lacuna, containing several bioplasts. One of these I figured as early as 1861. See Plate VIII, fig. 48. "The structure of the tissues," a course of lectures given at the Royal College of Physicians, 1861. The bioplasts of adjacent lacunæ increase in the same manner, and by degrees lamina after lamina of the osseous tissue of the Haversian rod dissappears, and in place of hard bone, we find soft pulpy growing bioplasm occupying what is now the "Haversian space," and filling up the interval between the vessel of the Haversian canal and the boundary formed by the circumferential portion of surrounding Haversian systems, which will in their turn have to undergo the same process of disintegration. The bioplasts do not effect the removal of the bone, as might be supposed, by the formation of an acid fluid or by developing some substance that possesses solvent properties. Upon the whole it is more probable that the change is due to a mechanical rubbing away rather than to the action of a chemical solvent. It seems to me most likely that by the incessant movements of the bioplasm in very close contact with the material to be removed, excessively minute particles are gradually rubbed off, as it were. The smallest molecules of the

matter in this minutely disintegrated state are so very small that the fluid containing them in suspension would exhibit the same properties as that in which small particles were actually dissolved, for the particles in suspension would traverse animal membrane with the fluid, and would be brought into sufficiently intimate contact with the bioplasm to be taken up and appropriated by the living matter itself. By this farther change particles do become chemically altered, and the constituent elements separated from one another and prepared for recombinations and the formation of substances, it may be, of a kind totally different from those which existed before.

221. Reparation of bone.—The great importance of this subject to the surgeon has led to many very interesting researches. From the time of Duhamel to the present day, the several steps of the process by which new bone is formed have been ably elucidated in all that relates to their more obvious characters by the investigation of distinguished scientific men and practitioners. When a fracture occurs, blood is, of course, effused into the wound, both from the ruptured vessels of the bone itself, and from those of the surrounding structures participating in the injury. This blood soon undergoes change. Its colouring matter is absorbed, and its bioplasm particles (white blood corpuscles) multiply. The fibrin at length disappears, being appropriated by the developing bioplasts, and in its place a form of fibrous tissue is produced. This at length undergoes calcification, and from the fourth to the sixth week a soft temporary bone, termed by Dupuytren *provisional callus*, results. This is slowly replaced by the development of permanent bone (*permanent callus*) from the growth and multiplication of the bioplasts of the torn periosteum of the original bone.

222. Of inflammation of bone.—In the develop-

ment of bone, in the removal of old Haversian systems, and in the formation of new ones, in the union of fractured ends of bones, in caries, and in the formation of bone cancer, the bioplasts or masses of living germinal matter are the active agents. If bone is to be *absorbed* these little masses of bioplasm multiply very rapidly, and increase at the expense of the surrounding bone. On the other hand, if bone is to be *formed*, it has been shown that the masses of bioplasm having increased in number for a time, cease to multiply. Each increases in size, and the outer part slowly undergoes conversion into formed material, which in its turn becomes gradually impregnated with hard calcareous salts. The harder the bone is to be, the slower must this process proceed. Now in *inflammation of bone* the bioplasts of the lacunæ increase in size, and appropriate the formed material adjacent to them. Thus, a lacuna becomes much enlarged, and is found to contain several small spherical masses of bioplasm instead of one. The bone tissue between several lacunæ may be disintegrated and removed, and thus a space of considerable extent may be scooped out even in the compact tissue, and may be occupied by masses of bioplasm, resulting from the division of the bioplasts belonging to several lacunæ. This is one way in which an abscess in bone may originate.

223. Rickets and caries.—In these conditions the *vital* changes going on in osseous tissue are much more active than healthy bone, which lives and grows but slowly in comparison. The morbid processes are characterised by the increase of bioplasm, which grows too fast for the condensation of the tissue which is requisite for the production of true bone to take place. Here, as in all other cases, rapid change is associated with brief duration. The well developed normal lasting bone tissue is formed very slowly, and

the changes succeed each other in the most gradual, orderly, and regular manner.

In *rickets* the bioplasm grows fast, and a very soft kind of formed material results, which is not hardened, or only very imperfectly hardened by the infiltration of calcareous salts. The bone is, therefore, not resisting enough to support the superincumbent weight of the body, and yields, becoming bent and distorted, according to the direction of the pressure. In *caries*, the bioplasm of a part of a bone receives too large a supply of nutrient matter; it grows too fast, and lives upon the surrounding tissue which has been already formed.

224. Of the death of bone.—In *necrosis*, the death of the bioplasm of many lacunæ takes place. It is easy to conceive that such a result must ensue if the supply of blood be cut off; for the currents of fluid, which during life flow through the canaliculi, and permeate every part of the bone, cease, and the bioplasts die. Changes in the small trunks which supply the Haversian vessels, ending either in their obstruction, as, for example, by clots, or their obliteration by pressure, exerted upon them, as from the growth of adventitious tissue around, may cause necrosis of a considerable extent of osseous tissue. Thus effusion into the deeper and more spongy portion of the periosteum, as occurs in the formation of a node, may cause the occlusion of some of the vessels passing from this membrane into the compact tissue. The passage of blood through these vessels being interfered with, the bioplasm of all that portion of bone receiving nutriment from them must die, and a piece of bone of considerable size become "necrosed." Immediately around this the nutrient matter would flow more freely, but of course less regularly. In consequence, the bioplasm of the neighbouring lacunæ would grow much faster, and thus a vast number of bioplasts would result. These would even eat away,

as it were, but of course very slowly, the dead bone, which soon becomes surrounded by them. After the bioplasts have accumulated to a certain extent, many increase in size, produce formed material, which in its turn ossifies, and thus the piece of dead bone is at length imbedded in new irregularly formed bone. This process goes on, unless the whole of the dead bone (sequestrum) is removed by the process above referred to, or by surgical interference. Before the dead bone can be removed by the surgeon, he has in many cases to cut away very much of the new bone which has been produced. Now, it has been said that the dead bone acts as an irritant—as a foreign body—and that this is the reason why the bone increases around it. Such a doctrine is still strongly maintained, although no one has been able to show exactly what is meant by the supposed "irritation."

225. Nature of irritation and excitation.—It has been assumed that an irritant or excitant is always necessary to increased action, that by this "irritant" the living cells are "excited" to live faster than usual. For this increased activity, all that is really required is *a more free access of nutrient matter*. The so-called "irritant," instead of "exciting," acts in the most passive manner possible. It permits pabulum to have freer access to the living bioplasm. By it the restrictions under which growth normally takes place are to some extent removed. There is no "excitation to increased action" at all. The more freely living matter is supplied with pabulum, the faster it grows. "Increased action" in a living structure results from the *removal of restrictions*, as occurs when the *rupture*, *perforation* or *softening* of the "cell-wall" or "intercellular substance," takes place. The nutrient pabulum comes more readily into contact with the bioplasm which grows faster, but not in consequence of "*stimulation*," "*excitation*," or "*irritation*."

LIST OF MICROSCOPICAL SPECIMENS ILLUSTRATING LECTURE VIII.

No.		No. of diameters magnified.
58.	Ossifying cartilage, kitten; masses of bioplasm near ossifying surface, arranged in rows and increased in size as they approach the part ossifying ..	130
59.	Ossifying cartilage, temporal bone; frog. Observe the globules of calcareous matter deposited around the masses of bioplasm	215
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61.	Formation of bone beneath periosteum, ossifying femur, kitten. Observe the bioplasm in the very large lacunæ	215
62.	Cancellated structure and cancelli bone, pig; showing bioplasm in lacunæ	130
63.	Fully formed bone, pig; showing bioplasm of lacunæ, canaliculi, and fibrous arrangement of the fully formed bone	215
64.	Bioplasm in very large lacunæ in course of formation, frog	215

LECTURE IX.

Of the Bioplasm of Nerve Tissue—Nerve Tissue in the lowest Organisms—The active part of a Nerve-fibre—Fine Nerve-fibres—Ultimate Networks—No ends to Nerves—Dark-bordered Nerve-fibres—Pale Fibres—Course and distribution of Nerve-fibres—Nerve Centres—Central Nerve Cells—1. Angular or Caudate Nerve Cells—2. Spherical, Oval, and Pyriform Nerve Cells—Nerve Cells with a straight and spiral Fibre—Probable nature of spherical and oval Nerve Cells—Nature of the Nerve Current—Arguments in favour of Peculiar Force—Arguments in favour of Nerve Current being Electricity—Action of the Bioplasm of Nerve Tissues—Conclusions concerning the Structure, Arrangement, and Action of a Nerve Mechanism.

Of Nerve-fibres.

226. Importance of bioplasm in the highest tissues.—It is only when we come to study the phenomena of the highest tissues that we begin to realise the vast importance of bioplasm in the changes that occur during each moment of existence. We have seen that the simplest tissue with which we are acquainted, as well as the most complex, owes its formation to bioplasm; but in many textures the bioplasm performs no other office. In every part of the nervous system, however, more especially at the peripheral distribution and central origin of all nerves, active changes of the most important kind are effected through the agency of the bioplasm, and these continue throughout life. Indeed, in some

instances, nerve action, which is dependent upon changes in the bioplasm, never ceases for a single moment from birth to death. The active phenomena of the nervous system are entirely due to *vital* actions, and the matter which is concerned in these vital changes is invariably the bioplasm We shall therefore have to consider the general structure and mode of growth of nerve tissue, and especially the relation which its bioplasm bears to the formed material of nerve-fibres and cells. The mere anatomical question has, indeed, a most important bearing, for, until it is decided, we cannot hope to carry on investigations with any great chance of success into the real nature of nervous actions. Various opinions have been advanced concerning the structure and arrangement of nerves in the lowest animals, and the fanciful suggestion that nerve matter may be in solution or in a molecular state, diffused through the general tissues of the body, has scarcely yet been abandoned. On the other hand, it has been affirmed that no fibre ought to be regarded as *nerve* which does not exhibit the dark-bordered character. This strange dictum involves the acceptance of the doctrine that nerves pass into, and are continuous with, other tissues of the body, and act by reason of this continuity of material substance. But I hope to convince you that we may now discard both these extreme doctrines, because we are able to define, and with considerable accuracy, what is essential to nerve structure.

227. Nerve tissue in the lowest organisms.—It might be supposed that we should be able to form a correct idea of the essential structure of a nervous apparatus if we appealed to some of the lowest organisms in which the existence of nerve tissue might be fairly assumed. In them it would be supposed that we should meet with a nervous system in a very simple condition. But it unfortunately happens that in these lower forms of life the nerve-fibres are so very deli-

cate as to be, under ordinary circumstances, invisible. Nor is it surprising that the difficulty of detecting them has induced some to adopt the hasty and, it must be admitted, unjustifiable, inference, that many creatures which exhibit combined and complex muscular movements are altogether destitute of nerve-fibres, but that the nerve matter of their bodies exists in a diffused and fluid state, or in the form of minute disconnected particles disseminated amongst the tissues.

Now, if the tissue of the arm of an Actinia, or sea anemone, be carefully examined after successful staining, § 68, multitudes of minute oval bioplasts (nuclei), taking different directions, will be observed amongst the muscular fibres, as well as in the external investment. The disposition of these would receive explanation if they were connected together by delicate threads. Here and there in a very thin specimen a very delicate film can indeed be discerned passing from one bioplast to its neighbours. A precisely similar arrangement is seen upon the muscular tissue of the suckers of the common starfish, in the skin of the oxfluke, and in the true skin of the leech and earth-worm. In these last I have been able to trace very distinctly the connection between the bioplasts and the excessively delicate inter-communicating threads, as well as to demonstrate the passage of the finest fibres into unquestionable nerves. In insects, and especially in the maggot and common bluebottle, I have also succeeded in tracing the connection. In the peripheral organs of the perfect fly, and in many tissues of the mollusca, especially over some of the muscles, I have been able to separate an extremely delicate tissue, consisting principally of nerve cells with very fine fibres passing from them, and crossing and interlacing in every direction, constituting what may be truly described as a nerve membrane of extreme delicacy. We shall find in the peripheral parts of the nervous system of man and

the higher animals at an early period of development, a precisely similar arrangement. In this delicate membranous structure no separate nerve cords or fibres can be detected, but delicate tracks crossing one another at various angles may be discerned. Running in the same direction as the tracks are oval masses of bioplasm. The lines, I believe, indicate the paths taken by the nerve currents as they traverse the delicate nerve tissue in passing to and from the nerve centres.

228. Irreconcileable opinions concerning the structure and action of a nerve apparatus.—At this present time there is the greatest disagreement among authorities upon fundamental questions. It is not even determined whether nerves terminate in ends or form continuous circuits,—nor whether they influence tissues by reason of their being in structural continuity with them or merely indirectly, in consequence of currents passing along the nerve-fibres situated at some short distance from the particles of tissue to be influenced. And it is not known whether the influence is produced by the passage of a continuous current varying in intensity, or by an interrupted current. Nor is there more accord as to the origin of nerves in centres; some holding that the fibres invariably originate in cells; others, that some cells have no fibres at all connected with them. And of those who admit the first proposition, some think the fibre comes from the body of the cell, while others profess to have traced it into the nucleus. Some even assert that they have seen the fibre emanating from the nucleolus. Or, again, concerning the fibres, which unquestionably originate in nerve cells, it has been stated that some pass into nerve-fibres, while others have no special relation to nerves at all.

229. The active part of a nerve-fibre.—It is most remarkable how very closely the nerve-fibre in the lowest and most simple creatures which possess a

nervous system resembles the active part of the nerve-fibre in the higher animals, especially at an early period of development. The active part of the nerve-fibre in adult vertebrata invariably consists of a very delicate compound thread which exhibits a slightly fibrous character, and is composed of an oleo-albuminous material. Connected with the threads at varying intervals are oval masses of bioplasm. In highly sensitive peripheral nerve-organs, and in the motor nerves of muscle, these masses of bioplasm are very numerous, and, in some cases, are almost continuous with one another; but in less sensitive textures the masses of bioplasm are often separated from one another by a distance of $\frac{1}{100}$th of an inch or more. In all cases these bioplasts or "nuclei" are situated very close together at an early period of development, and at first the tissue which represents nerve consists of bioplasm only. As the tissue advances towards maturity, the masses of bioplasm become gradually separated from one another by a greater extent of fibre, but at all periods of life and in all peripheral branches of nerves these bodies are present.

230. Fine nerve-fibres compound.—The fine nerve-fibre sometimes appears as a very distinct fibrous structure, which, were it not actually traced to unquestionable nerve-fibres, might be easily mistaken for fibrous or connective tissue; sometimes as a very delicate expansion of such extreme tenuity as to be demonstrable only after it has been partially altered by chemical reagents, and the oily matter separated from it in the form of granules or globules, which can be very easily traced. Fibres often pass off at an angle from these fine nerve-fibres, and divide and subdivide, joining others, so as to form a network, the meshes of which vary much in diameter in different cases. Every one of these delicate fibres of which some are not more than the $\frac{1}{100,000}$ of an inch in diameter, must be regarded as composed of still

finer fibres, which, after leaving the branch under observation, pursue opposite directions. In using the term *network*, therefore, I do not mean to imply that fine nerve-fibres unite with each other after the manner of capillaries, but merely that the *bundles* of fibres are arranged like net-works. The fibres composing the bundles do not anastomose. In lace the appearance of such a network of fibres is produced; but every apparent thread is composed of several, each of which pursues a complicated course, and forms but a very small portion of the boundary of any one single space.

231. No ends to be demonstrated.—Proceeding from the finest nerve-fibres, no fibres exhibiting *ends* or terminal extremities can be detected, and the general conclusion to which we are led is, that nerves are arranged to form continuous strands of fibres which pass amongst the elementary parts of the tissues, but neither become continuous with them, nor terminate in free extremities in or upon them. The active part of a peripheral nerve-fibre with its bioplasm is represented in many of my drawings published in the *Phil. Trans.* 1861, 1862, 1867.

In all cases, as far as I can ascertain, the ultimate terminal fibres are pale and granular, exhibiting nuclei at varying intervals, but are distributed upon precisely the same plan.* I am of opinion, therefore,

* Not many years since, numerous observers considered that no fibre could correctly be termed a nerve-fibre which did not exhibit the dark-bordered character (§ 233) and many real nerve-fibres were regarded as fibres of connective tissue. But since I demonstrated the very fine nerve-fibres in many different textures, and showed that in all cases the really active peripheral part of the nerve was the terminal plexus, composed of very fine compound fibres often less than the $\frac{1}{100000}$th of an inch in diameter, numerous memoirs have appeared in Germany in which the authors endeavour to prove that exceedingly fine fibres pass off from what I look upon as the *terminal plexuses*, and end or terminate in epithelial cells, or form very minute networks upon and amongst the cells.

that there is not such a thing as a true *end* to any nerve-fibre. I must, however, admit that almost all the observations which have been made in Germany during the last few years are opposed to this view. Memoir after memoir has been published for the purpose of proving that nerves exhibit terminal extremities in several motor and sensitive organs. As investigation proceeds, this controversy becomes more interesting and exciting. Although my opponents are many and powerful, the facts in favour of my own view are now very numerous and almost every new investigation I attempt enables me to add more to the number. Moreover, my conclusions rest upon observations upon many different tissues and organs not only of vertebrata, differing widely from one another, but of numerous invertebrate animals. I cannot therefore yield. I am quite convinced that numerous specimens I have made fully justify me in maintaining the general proposition that in all cases the terminal distribution of nerves is a plexus, network, or a loop, and hence that in connection with every terminal nervous apparatus there must be

Pflüger has arrived at the conclusion that the nerves distributed to the salivary glands end by exceedingly fine filaments which pass into the epithelial cells and become connected with them or their bioplasts (nuclei); but I do not think that in this organ any nerve-fibres pass beyond the surface of the connective tissue upon which the secreting bioplasts lie. I have never been able to convince myself that nerves pass to the epithelial cells in any of the situations indicated, nor have I seen any preparations at all conclusive. On the other hand there are many facts opposed to this view. Upon the whole, the evidence, so far, is strongly in favour of terminal networks beneath the epithelium of such tissues as mucous membrane and secreting glands. And as the act of secretion,—the production of peculiar compounds by bioplasm differing entirely from the materials out of which they were made,—is certainly performed in many cases without nervous agency, much stronger evidence than any yet advanced ought to be adduced before the conclusion that nerves act directly upon the secreting cell is accepted.

at least two fibres; *and that in all cases there exist complete circuits into the formation of which central nerve cells, peripheral nerve cells, and nerve-fibres enter.* All these elements are in structural connection with each other. ["How to Work with the Microscope," 4th Ed.]

232. Of plexuses and terminal networks.—Every one agrees that the larger nerve trunks are in many instances so arranged as to form plexuses or networks, to which various names have been assigned by anatomists, according to their position, general form, origin, &c.; but it was supposed that in many cases nerves pursued an almost direct course to their ultimate distribution, where they terminated in free extremities, in cells, or by becoming continuous with the texture they influenced. More careful observation has, however, demonstrated that all nerves before they reach their finest ramifications form microscopic networks or plexuses, arranged upon the same plan as the coarser networks above alluded to; and I have been able to demonstrate that the *fine ramifications* themselves constitute a *plexus or network, in which the component ultimate fibres are arranged in much the same manner as the large dark-bordered fibres entering into the formation of one of the ordinary plexuses.*

Careful observations upon the arrangement of particular nerve plexuses in the same texture at different periods of development have convinced me that the ultimate terminal plexus of the embryo becomes the plexus composed of coarser fibres of the infant and child, and the plexus made up of bundles of compound fibres of the adult. New *ultimate nerve plexuses* gradually come into existence as the constituent fibres of those previously formed grow and slowly become converted into thick nerve-fibres. That a continuous development of new nerve-fibres takes place in the adult has been proved beyond ques-

tion by facts demonstrated in many of the textures of man and the lower animals. The arrangement is the same as regards sympathetic, and spinal motor and sensitive, nerve-fibres—except that in the latter the constituent fibres of the plexuses one or more removes from the terminal plexus are dark bordered. ("How to Work with the Microscope," 4th Ed.)

233. Dark bordered nerve fibres of the trunks of nerves.—Every peripheral nerve network is connected with its nerve centre by fibres, and whenever the distance between the centre and peripheral organ is considerable, the nerve-fibres are protected from each other, and from the tissues through which they pass, by a thick layer of oleo-albuminous matter, which forms an investment to each bundle of delicate fibres, by which it is insulated and separated from its neighbours, and from other structures, by a distance equal to from five to twenty times its own diameter. When the trunks pass through narrow canals, as through holes in the cranium, this insulating protective covering is much reduced in thickness, so that a large bundle of nerve-fibres is made to pass through a space not more than one-fourth of the diameter which the nerve trunk possesses in other parts of its course. The fibres which have this thick covering are known as "*dark-bordered fibres*," from the dark double-contour line they always exhibit when examined in water or weak serum; the covering itself is known as the "white substance of Schwann," or the "medullary sheath." The double-contour line is not seen in specimens mounted in glycerine or syrup. When one trunk diverges from another, many of these fibres divide, one of the resulting subdivisions continuing onwards in the trunk, while the other passes off to help to form the branch trunk. I have figured many of these branchings. See Plate II, figs. 3, 4, p. 182.

234. Of the pale nerve-fibres of the sympathetic system.—In cases in which the distance between the nerve centre and the peripheral distribution of the nerves is not very great, the compound fibres are not insulated by a "medullary sheath." In many of the nerve fibres belonging to the so-called sympathetic system there is no "medullary sheath," or "white substance of Schwann." Where, however, the ganglia or peripheral organs are connected with nerve centres at a considerable distance off, a number of fibres having this investment are found; so that amongst the sympathetic nerve fibres, we find dark-bordered nerve-fibres just as commonly as pale fibres occur in the trunks of spinal dark-bordered nerve-fibres (§ 235). In the bladder of the frog I have observed that where the distance between the ganglion and the peripheral distribution of the nerve fibres is considerable, the fibres have the dark-bordered character while, on the other hand, if the peripheral distribution is near the ganglion, the ultimate nerve-fibres are connected with the latter by pale fibres only.

235. Of fine fibres running with the dark-bordered nerve-fibres.—I have described and figured very fine nerve-fibres running close to the dark-bordered nerve-fibre in the same sheath with it, when there exists a sheath, and in the bundles of dark-bordered nerve-fibres near their distribution, several such fine fibres may be discerned. These fine fibres themselves result from the division of dark-bordered nerve-fibres. Sometimes, a dark-bordered nerve-fibre divides into one dark-bordered, and one fine fibre. The fine fibres are in fact the continuation of the dark-bordered fibres, and are very near the point of ultimate distribution. These fine fibres accompanying dark-bordered nerve fibres, have not been described or figured by other observers, and are quite undemonstratable in specimens prepared according to the methods usually followed, though they are very distinct indeed in specimens,

carefully prepared and mounted in glycerine, or in strong syrup. The fact of the existence of such fibres is of great importance with reference to the question of the mode of termination and action of nerve fibres, and must influence much the conclusion we adopt concerning the essential structure of a nervous apparatus. This part of the question has been discussed in papers published in the "Medical Times and Gazette," January and February, 1867; see also, "Archives of Medicine," 1862–4; "Croonian Lecture," 1865.

236. Of the axis cylinder.—What appears as the single core or "axis cylinder" of a nerve fibre in the nerve trunk is *formed by the coalescence of very numerous fine fibres, each coming from a different central nerve cell.* In following a single dark-bordered or other nerve fibre towards centre or periphery, we find that it divides and subdivides into a great number of fibres which pursue different and often opposite directions, one passing towards the centre, and the other to the periphery. And these are implanted in different parts of the nerve centre or peripheral organ at considerable distances from one another.

237. Advantages of the subdivision and interlacement of nerve fibres.—If, therefore, one branch of a nerve fibre be destroyed by injury, accident, or disease, there ought to be neither *complete* paralysis nor *complete* loss of sensation even of the smallest portion of the body, but, on the contrary, a very slight effect should be produced upon parts situated perhaps at some distance from one another. Experience and observation have proved such to be the fact. By the very free crossing and interlacing and the frequent change in the course of nerve fibres in all nerve centres, very serious damage to any one organ or part of an organ by local disease or injury, is effectually provided against. Were all our faculties exactly localised and the great nerve organs com-

posed of numerous distinct parts, each having a separate office, injury to one of these, or even to a part of it, would involve the complete loss of the particular faculty of which it was the seat. As it is, even very extensive disease sometimes impairs, and only to some very slight extent, the actions of a number of nervous organs without completely destroying the activity of any one. Nerves often reach their ultimate ramifications after pursuing a most circuitous course, so that in many cases a nerve may be divided without sensation being destroyed in the skin to which its peripheral branches are distributed, because this is supplied by nerve twigs, derived from other trunks tolerably near its central origin or peripheral distribution, which reach the same spot after pursuing a less direct, and perhaps much more circuitous course. Plate I. Cases have been recorded by Richet, of La Pitée, Paris, Dr. J. C. Nott, of New York, and Mr. Savory, in which sensibility was preserved in the parts supplied by so large a nerve as the musculo-spiral nerve, after it had been completely divided (New York Medical Journal, June and August, 1868).

238. Fundamental and essential characters of a nervous system.—In many of the lower animals I have seen very delicate fibres and masses of bioplasm arranged to form an extensive network amongst the tissues, and in some I believe the entire "nervous system" consists of such a network extended through all parts of the organism. In the common starfish and some other members of the Radiata I have seen distinct indications of the existence of a structure such as I have described, and I have no doubt that when our methods of preparation have been still further improved we shall be able to demonstrate the nerve-tissue wherever it exists, and distinguish it with certainty from the tissues amongst which it is distributed.

Plate I.—PERIPHERAL TERMINAL NETWORKS.

Fig. 1.

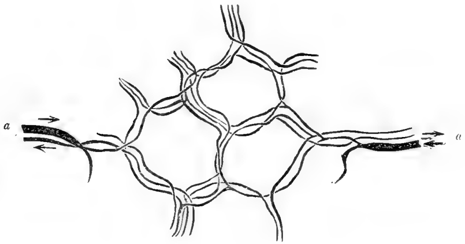
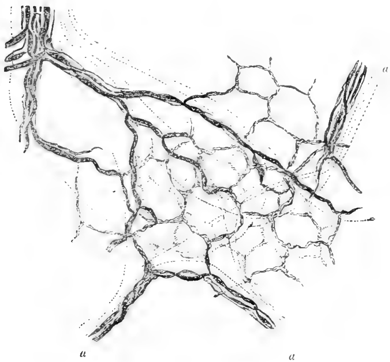


Diagram to explain the author's view of the arrangement of the finest nerve-fibres composing the "networks" *a a* dark-bordered and fine nerve trunks.

Fig. 2.



Drawing to show the manner in which plexuses or networks of fine nerve fibres are formed. The course of the numerous nerve currents to and from the trunks is indicated by the dotted lines *a, a. a a* dark-bordered nerve fibres and fine fibres running with them.

But, when to these observations upon the simplest creatures are added, the positive facts demonstrated by me with reference to ultimate distribution of the finest nucleated nerve fibres and their bioplasts, in a number of tissues of vertebrate animals, an amount of evidence is appealed to, which ought not to be disregarded. The conviction forced upon the mind is irresistible, that in their general structure, ultimate arrangement, and mode of action, the nerves of different classes of animals from the highest to the lowest, and the nerves distributed to all the tissues of the same animal exhibits so many points in common, that we may conclude the arrangement is the same in principle in all. The active part of every peripheral nerve apparatus is an uninterrupted network of extremely delicate fibres, which are structurally continuous with the masses of bioplasm in the nerve centres. These last, however, in the lowest classes being as it were so spread out as to render it difficult or impossible to define which part of the nervous system should be considered *peripheral*, and which *central*. The arrangement is such that it might be correctly described as consisting of multitudes of closed circuits which are uninterrupted, and are structurally continuous in every part.

In many terminal organs, no doubt, the appearances are such as to justify upon superficial examination the conclusion that the nerves really form true ends. In many instances it has been distinctly affirmed that one single nerve fibre was lost in a single terminal cell or other organ; and as regards striped muscle it has been stated as a fact of observation that such is the case, by a large number of observers. If this were so, we should be compelled to conclude that the single nerve fibre was really terminal. But in every single instance in which I have had the good fortune to obtain good specimens of such organs, I have been able to detect more than one nerve fibre. At the

base of the peripheral organs of taste the nerve fibres have been actually seen to pass in opposite directions, Plate II, fig. 1, and in the so-called end organs of muscles, Lecture XI, I have demonstrated two or more fibres in numberless instances. The evidence that I have brought forward in favour of the conclusion, that nerves form continuous and uninterrupted cords with bioplasts in their course, and continuous with the matter of which the fibre is composed, cannot, I think, be controverted or explained away, though I dare say few will be disposed to accept my conclusions just yet.

239. The course and distribution of nerve fibres.—As already stated, all my observations tend to the inference that nerves never end, and I think that the conclusions that have been arrived at in favour of the idea of terminal extremities and terminal organs have resulted from the examination of inconclusive specimens or from erroneous observation. A careful consideration of the facts observed concerning—1, the structure of certain peripheral organs favourable for investigation; 2, the distribution of nerve fibres in nerve centres; and 3, the connection between the fibres and central nerve cells, forces upon my mind the conclusion that the nerve fibres composing the nerve trunks, and those finer branches which unite to form dark-bordered nerve fibres, may be arranged in the following subdivisions, according to their distribution:—

1. Nerve fibres passing towards a centre—*Afferent fibres.*

2. Nerve fibres passing from a centre—*Efferent fibres.*

3. Nerve fibres connecting nerve centres with one another—*Commissural central fibres.*

4. Nerve fibres connecting the peripheral ramifications of nerves and peripheral nerve organs with one another—*Commissural peripheral fibres.* Plate II, fig 1.

Plate II.—PERIPHERAL ORGANS AND COMPOUND NERVE TRUNKS.

Fig. I.

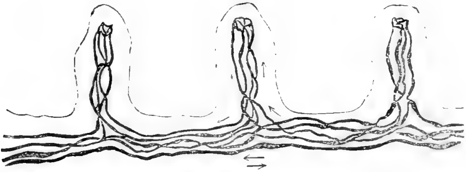
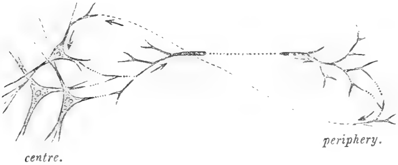


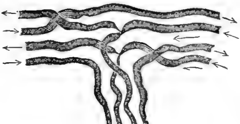
Diagram of three papillæ from the frog's tongue, to show the arrangement of the nerve fibres. Each papilla is connected with its neighbours by fibres, as well as with the nervous centre. Amongst these are, 1, afferent fibres; 2, efferent fibres, 3, commissual peripheral fibres; and 4, commissual central fibres.

Fig. 2.



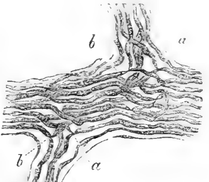
Central and peripheral portion of spinal nervous system, showing sub-division of dark-bordered fibre into a large number of fibres as it approaches both centre and periphery. See also Pl. III, fig. 1, p. 187.

Fig. 3.



The course and division of individual dark-bordered nerve fibres showing that one of the fibres resulting from the sub-division of a fibre passes on in the direction of the original fibre, while the other passes into the branch which diverges from the trunk.

Fig. 4.



A nerve dividing into three branches. From the breast muscle of the frog. At *a* and *b* individual dark-bordered fibres are seen to divide, the fibres resulting from the sub-division passing onwards in different branches. Copied from an actual specimen.

These different classes of nerve fibres have been represented in figures 1, 3, and 4, Plate II. It will be found that the results of investigation into the structure of terminal organs, the fact of the divisions of the trunks of nerves as they pass towards nerve centres or towards their peripheral distribution, as well as the arrangement of nerves and nerve cells in the nerve centres, strongly support the conclusion that nerves do not in any case divide into single fibres, each having a terminal extremity, or end by becoming continuous with other tissues. Numerous facts indicate that nerve fibres never end.

Of Nerve Centres.

Next, I must draw attention very briefly to the minute structure of nerve centres, which invariably contain a vast number of "nerve fibres" and "nerve cells," often of large size. These cells, in some cases, have a highly complex structure. The "nerve centre," in fact, exhibits the essential structures characteristic of the peripheral portion of the nervous system, except that in the nerve centres of man and the higher animals, the elementary parts or "cells" are, for the most part, much larger than those found in peripheral organs. In the nerve centre a great amount of tissue is compressed into a comparatively small space, so as to form a collection, knot or ganglion. It has been shown that, in the lowest animals in which nerves are to be demonstrated, there is not this distinction between the central and peripheral parts of the nervous system. The nerve tissue seems almost uniformly distributed. In the higher invertebrata and in the vertebrata, however, it is probable that the nerve tissue collected in the nerve centres exceeds in amount that which is spread out amongst the tissues in all other parts of the organism.

240. Central nerve cells.—Each central nerve cell consists of a mass of bioplasm surrounded by

formed material, which last is drawn off at *two or more points* into fine threads,* These divide and subdivide into still finer ones at a short distance from the cell, and are, in fact, processes of the nerve cell which become nerve "fibres." The processes invariably take opposite directions soon after they have left the "cell."

Nerve cells may exhibit important structural peculiarities, so that it is even possible to say, in some instances, after examining a single cell, from what central organ it had been taken.

In vertebrata there are two principal kinds of central nerve cells which are very distinct from one another, and probably differ in function not less than they do in structure. These are, 1, *The Angular or Caudate Nerve Cells, and* 2, *The Oval, Pyriform or Spherical Nerve Cells.*

241. Angular or caudate nerve cells are characteristic of the great central nerve organs of vertebrata, the brain and spinal cord, and attain their maximum of development in the highest mammalia and man. In many of the lower vertebrata these cells are remarkably small, while the other class of cells, on the other hand, is of very large size. If we examine the caudate cells in the gray matter of the spinal cord and medulla oblongata of mammalia, we see lines traversing the cells from each of the many fibres connected with them, and passing to every other fibre. (*Proceedings of the Royal Society*, 1864.) I endeavoured to show that these lines, which were rendered evident by the slow action of acetic acid indicated the paths taken by the nerve currents which traversed the cell. Plate III, fig. 2.

It is an interesting circumstance, and strongly corroborative of the truth of the views just advanced, that at the very time I was making out the

* It is probable that no nerve cell exists which has only *one single fibre* connected with it.

PLATE III.—CAUDATE NERVE CELLS.

Fig. 1.

Diagram to show the course of the fibres which leave the caudate nerve cells. *a a* are parts of two nerve cells, and two entire cells are also represented. Fibres from several different cells unite to form single nerve fibres *b b b*. In passing towards the periphery these compound fibres divide and sub divide, the resulting sub-divisions passing to different destinations. The fine fibres resulting from the sub-division of one of the caudate processes of a nerve cell may help to form a vast number of dark-bordered nerves, but it is, I think, certain that NO SINGLE PROCESS EVER FORMS ONE ENTIRE AXIS CYLINDER.

Fig. 2.

A diagram of a caudate nerve cell, showing the principal lines which diverge from the fibres at the point where they become continuous with the substance of the cell. These lines may be traced from any ONE FIBRE ACROSS THE CELL, and one or more of them may be followed into EVERY OTHER FIBRE which proceeds from the cell. The tracts are not connected with the bioplasm of the nerve cell.

peculiar anatomical fact recorded in my paper, Professor Alexander Bain, looking at the subject from a totally different side, was led to conclusions concerning the arrangement of the nervous mechanism agreeing in all important particulars with my own, which had been deduced from observations upon the tissue itself.

Deiters, Boddaert, and other observers, have stated that one dark-bordered nerve fibre enters each of these cells. If this be so, we may consider the axis cylinder as splitting up in the cell into a number of branches, some of which pass into every one of the so-called "protoplasm" fibres which leave the cell and are supposed to terminate a short distance from it. My own observations lead me to conclude that *all* the fibres are composed of the same material and exhibit precisely the same structure and refractive power, but that one fibre (Deiters' dark-bordered fibre) does not divide until it has passed some distance from the cell, while the others give off branches much closer to it.

Connected with the cells of the gray matter of the brain, particularly of the sheep, is one long fibre which may often be followed for the distance of the tenth or twelfth of an inch without giving off a single branch. The other fibres, on the contrary, break up into a considerable number of ramifications near to the cell. I cannot agree with Deiters and Max Schultze in regarding these fibres as of a totally different nature from the long one. Although in Deiters' figures the long dark-bordered fibre is represented as if it were altogether different in structure from the other fibres of the cell, I do not discover this difference indicated in the beautiful photograph of Boddaert, from which it appears to me all the fibres of the cell possess the same refractive power. This could not be the case if one were "dark-bordered" and all the rest consisted of what these observers call "protoplasm." The

course of the fibres which result from the division and sub-division of the processes of the caudate nerve cells, according to my view, will be understood if fig. 1, Plate III, page 187, be referred to. All the fibres of every cell divide and subdivide into finer fibres which are continued to peripheral parts.

It is probable that the caudate nerve cells are not *sources* of nerve force. These cells are fewer in number and comparatively insignificant in the lower vertebrata, particularly batrachia and fishes. In the invertebrata they do not exist at all, and it is doubtful if any "cells" precisely corresponding to them are to be found in their stead.

242. Bioplasm of the nerve cell.—The bioplasm of the nerve cell is embedded in the material which exhibits the lines crossing in all directions, and no doubt this substance is formed from it; but, as far as I have been able to ascertain, no nerve fibre arises from, or is connected with, the bioplast (nucleus or nucleolus). It appears probable that the caudate cells are the stations at which nerve fibres pursuing many different directions decussate and change their course. Plate III, fig. 2, page 187. Plate IV, figs. 1 and 2.

243. Of the spherical, oval, and pyriform nerve cells.—The nerve cells belonging to this class have a structure very different from that of the caudate or angular nerve cells. The fibres, instead of radiating from the cells and appearing as if drawn out from them, encircle them, and pursue a very circuitous course after leaving the cell. They are curved and coiled, and are of much greater length than is necessary simply to traverse the space through which they may be traced. The matter of which the fibres are composed is continuous with that of the cell, and the facts observed justify the inference that the fibres are continually growing, or, in other words, that the matter at the outer part of the cell gradually undergoes con-

Plate IV.—STRUCTURE OF A NERVOUS MECHANISM.

Fig. 1.

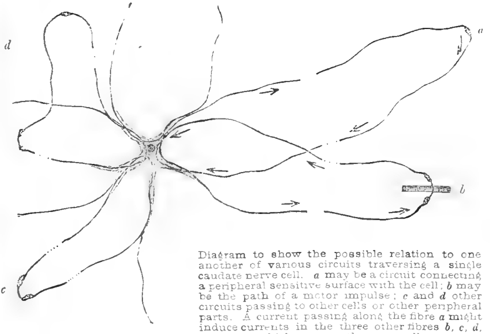


Diagram to show the possible relation to one another of various circuits traversing a single caudate nerve cell. *a* may be a circuit connecting a peripheral sensitive surface with the cell; *b* may be the path of a motor impulse; *c* and *d* other circuits passing to other cells or other peripheral parts. A current passing along the fibre *a* might induce currents in the three other fibres *b*, *c*, *d*, which traverse the same cell.

Fig. 2.

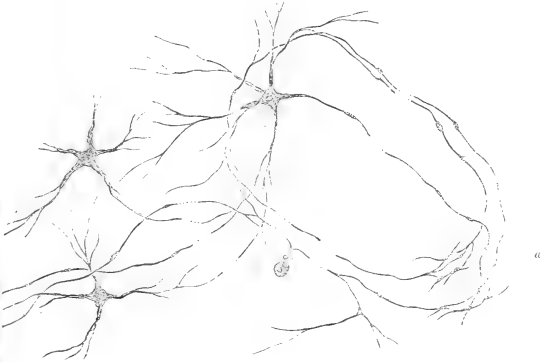


Diagram to show possible relation of fibres from caudate nerve cells of the spinal cord, and fibres from cells in ganglia, as, for example, the ganglia on the posterior roots. *a* is supposed to be the periphery; the cell above *b* one of those in the ganglion. The three caudate cells resemble those in the gray matter of the cord, medulla oblongata, and brain.

version into fibre, which process continues during the life of the cell. It seems as if the cell revolved, and at the same time had spun off fibres from its peripheral parts. In many cases the fibre seems to unwind itself from the outer part of the cell, and in this situation the gradual multiplication of the oval masses of bioplasm which are ultimately seen in the unwound fibre may be demonstrated, and the youngest may be seen growing in the substance of the cell itself, near the surface.

In man and the higher vertebrata the cells of this class are found in all the ganglia of the so-called *Sympathetic*, and in the ganglia on the posterior roots of the nerves, the Gasserian ganglion, &c., which belong to the same division. They are nearly spherical, and are usually represented as spherical cells or globules lying amongst the fibres of the ganglion. Even to this day these cells are stated in many text-books to be invested with a capsule of connective tissue, sometimes as thick as the cell is wide, in which numerous nuclei are represented. These are supposed to have no connexion whatever with the nerve-fibres passing near them. Nothing could be more unmeaning than many of the statements made concerning the structure of the sympathetic ganglion cells. Nevertheless, they are repeated again and again, and the old drawings of thirty years ago are adduced in support of doctrines which are utterly untenable.

Some writers still insist upon the existence of "apolar" and "unipolar" nerve-cells in many parts of the nervous system, although the results of observation positively prove the existence of two fibres in the case of cells which had been previously regarded as unipolar and apolar. From the cells of the sympathetic ganglia of man and vertebrata several fibres proceed, and pass in different directions soon after they leave the cell. Bundles consisting of fibres from many different cells leave the ganglion from

different parts of its surface, and pass by circuitous routes towards their destination, each bundle being composed of fibres from many different cells situated in different parts of the ganglion.

Ganglia are extremely numerous in the sub-mucous tissue of the alimentary canal of all mammalia, and in the human subject multitudes may be demonstrated at short distances from one another.

Connected with the nerves in the pelvis of the kidney I have also demonstrated numerous ganglia of the same kind. From every one of these, bundles of nerve-fibres pass to be distributed to the cortex of the organ. The fine nerve-fibres of the kidney are distributed to vessels and also to the uriniferous tubes.

244. Of ganglion cells with a straight and spiral fibre.—The structure of the ganglion cells of the ganglia of the frog are remarkable. In the year 1863 I presented a paper to the Royal Society, in which I showed that each cell possessed at least two fibres, and demonstrated the interesting fact that these fibres pursued *opposite* directions in the nerve trunks into which they passed, one apparently going *towards* an organ, while the other went *away from* it in an opposite direction. One of these fibres formed a beautiful spiral coil round the other. In some cells there was but one spiral turn, but in others as many as eight or ten could be counted, while in some again, which were probably the oldest cells, the spiral turns were still more numerous. *The spiral fibre comes from the outer part of the body of the cell, and the straight fibre from its central part, so that the tissue of the first is in structural continuity with that of the last, the body of the cell being composed of matter which may be said to be drawn off in one part to form the spiral, and in another to form the straight fibre.*

245. The views of Arnold and others.—Each fibre had several bioplasts in its course, but these were more numerous in the spiral than in the straight

fibre, and were closest to one another in that part of the former which was still coiled round the cell, and formed, indeed, part of its substance. Some months after my paper appeared, J. Arnold, of Heidelberg, quite independently, and probably without having heard of my observations, described a spiral fibre in connection with the ganglion cells of the nerves of the frog's lung, but in the drawings accompanying his memoir (Virchow's *Archiv*, Band xxviii, plate x), both straight and spinal fibre *result from the division of a single nerve fibre.* In drawings illustrating a paper published in 1865 (Virchow's *Archiv*, Band xxxii), two years after my memoir was completed, he gives examples in which the two fibres are delineated distinct from one another, and he further states (contrary to my observations) that the straight fibre terminates in the nucleolus, while the spiral fibre is made to commence in a network of fine fibres ramifying over the surface of the cell, which are traced up to the nucleus. These drawings have a somewhat artificial look about them which is not quite satisfactory. Subsequently Courvoisier and many other observers have studied the same subject, differing from me principally as regards the origin of the fibres from the body of the cell, and from one another in several particulars. I have reinvestigated the matter, but have not seen appearances which will justify any modification of the conclusions detailed in my memoir. The original specimen from which the figure—since copied into most of the text-books—was taken, may still be examined ($\frac{1}{25}$th objective, magnifying 1800 diameters), and the drawing may be compared with the preparation.

New memoirs have more recently appeared in Germany, and some authors have expressed the opinion that my spiral fibre is connective tissue. It is not surprising that they should have looked at my drawings as the inventions of my imagination

instead of being copies of what I had actually seen, because it is quite certain, from their own representations of the structures seen by them, that they had been studying most imperfect and unsatisfactory specimens. One might fairly expect that before an author ventured to upset the observations of another, he would take proper steps to obtain good preparations. It is, however, quite unnecessary for me to reply to objectors or to try to convince sceptics, as the actual specimen from which my most complex ganglion cell was copied has been examined by a number of observers.

246. Probable nature of spherical and oval nerve-cells.—The oval and spherical cells characteristic of the sympathetic, of the ganglia on the posterior roots, &c., are seen at a very early period of development, and the ganglia in which they are found are very large and advanced in development as compared with other parts of the nervous system. At a time when these cells are well defined and probably active, the *caudate nerve-cells* are but small masses of bioplasm which may be easily passed over. In the lower vertebrata, when fully grown, these cells are many times larger than the caudate cells of the spinal cord, and in the ganglia of most invertebrata we find spherical and oval nerve-cells which, I believe, correspond with those under consideration. The early development of these cells and their large size at a time when the caudate nerve-cells are not to be distinguished, their constant presence, their growth and multiplication in the adult and probably at an advanced age, and their peculiar structure—at least in some animals—their situation as regards the nerves to which they belong, and especially the fact that these are the only cells constituting the nerve-centres upon which the rhythmic contraction of detached portions of the cardiac muscular tissue depends, have led me to look upon them

as the *sources* of nervous power, while I consider that the caudate nerve-cells are more probably concerned in the radiation of the nerve-currents.*

My views concerning the arrangement and probable mode of action of the two classes of cells will be understood if the diagrams in plate IV, be referred to. The reader must suppose that the part of the diagram representing the periphery is situated at a great distance from the central cells, instead of very close to them, as indicated in the drawing. The explanation under each figure should be read carefully.

247. Of the nerve current.—The nature of the nerve current is not known, but the general opinion of physiologists is, that it is some mode of force, perhaps, correlated with heat, electricity, &c., but not exactly identical with any form or mode of energy known or of which we have as yet any experience. The arguments upon which this view is founded appear, however, to me very inconclusive. In the first place, I would ask, if it is reasonable for a scientific man to *assume* the existence of new modes or forms of force. Secondly, much of the evidence we have unquestionably favours the view that the nerve current *is* electricity, for many, indeed most, of the phenomena familiar to us may be explained upon this view. Lastly, some physiologists have sought to account for the wonderful phenomena of the nervous system by supposing that some force or power of a peculiar and exceptional kind is at work in nerve systems only. Now, I shall endeavour to show that if electricity could be made to travel in different directions, and the currents combined in various ways and made to traverse series of conducting cords very specially arranged, according to design, the phenomena of nervous action might be accounted for without resorting to the hypo-

* See a paper by me in the "Microscopical Journal" for April, 1869, and "The Mystery of Life."

thesis of the existence of a peculiar power, or of some new mode or form of force not yet discovered.* It is at least not improbable that the varying effects noticed in connection with the nervous system may be determined by alterations in the intensity of the current, and in the conducting properties of the fibres, instead of being due to the transmission of *different kinds of nerve force*. One would have thought that it would be more in accordance with the doctrines of physical science to endeavour to explain the phenomena by the action of forces we know something about, than to attribute them to the influence of other forms or modes of force which are purely fanciful and fictitious. At any rate it will be time to call in the aid of such airy nothings when all attempts to explain the facts by known forces shall have failed.

But it is interesting to notice how often minds of the most rigidly physical tendencies seize upon purely conjectural hypotheses, and use them as if they were established truths. It has been surmised that nerve action depends upon a chemical change which is supposed to take place in every part of the nerve fibre. Mr. Herbert Spencer settles the question in the most summary way by boldly asserting that the axis cylinder of a nerve consists of some colloid "matter isomerically transformed with ease." He accounts for nerve action by suggesting that the protein substance of the axis cylinder "is habitually changed from one of its isomeric states to another,"

* Physicists and chemists see no difficulty whatever in assuming the existence of many modes of force of which they can form no conception, and think it very satisfactory to refer phenomena which they cannot understand to some at present undiscovered form or mode of ordinary motion; but if any one attributes these same phenomena to the influence of some equally undiscovered form of force having no connexion whatever with primary energy or motion, he is ridiculed, because, say the physicists and chemists, "there must be unity in kosmos!"

while he explains further that the matter of the nerve cell is the seat "of destructive molecular changes and disengagement of motion!"

248. Chemical theory of the nerve current.—A chemical theory was long held concerning the nature of muscular action, but it was at last admitted, as was, indeed, apparent from the very first, that muscles would have to be destroyed and reformed at a far more rapid rate than it was on other grounds reasonable to suppose possible, if the great amount of energy manifested during their action was really due to chemical decomposition of the tissue of the muscle itself. There was, in fact, no evidence whatever, except that which was distilled from the imagination of the chemist, for the conclusion that muscular tissue did undergo rapid disintegration and reconstruction. From my own investigations of muscular fibres in various animals, I felt quite sure at the very time when these chemical doctrines were in high favour, that the conclusions were thoroughly erroneous. From the study of muscular tissue at different periods of development, and the consideration of various circumstances connected with the growth of muscle and its relation to other textures in a variety of animals, particularly in the class of insects, I was convinced that muscle was a *slowly growing* tissue, and that the work it performed was certainly not due to the chemical decomposition of its material particles. Nevertheless the fact of the change in the reaction of muscle from alkaline to acid is still urged in favour of the doctrine, and some have affirmed that a similar change occurs in nerve. In spite of the statements of Liebreich, Heidenhain, and other observers to the direct contrary, the view that nerve energy is stored up in chemical compounds which undergo chemical change during nerve action is still taught. That such an idea should be stated at all betrays ignorance of the character of the axis cylinder of the nerve

itself. If we examine the axis cylinder, say, of the sciatic nerve of a frog, what do we find ?—a firm, tough, fibrous-like, flattened band, not easily torn, and evidently consisting of a tissue of slow growth ;—in fact, the very last characters we should expect to meet with in a tissue prone to rapid chemical change. Neither is a structure surrounded by ten times its thickness of oily matter (myelin) favourably situated for taking up new materials and quickly getting rid of products of decay. One of the least permeable substances in the body is the myelin of the nerve fibre, and yet through this must pass all the materials from the blood to renovate the disintegrated axis cylinder, if nerve action is due to chemical change in the nerve fibre itself.

249. The vibratory theory of nerve action.— Again, some think that nerve action depends upon the molecules of nerve fibres being thrown into vibration, and the axis cylinder of a nerve has been spoken of as if it had been proved to consist of a chain or chains of very minute spherical particles. But the axis cylinder is not composed of matter which would more readily propagate motor impulses than the matter of ordinary fibrous tissue. Moreover, it varies much in character and in thickness in different parts of its course. The impulses supposed would be much modified during their transmission. This theory leaves one of the most important facts connected with nerve fibres unexplained; for upon such a supposition what purpose could be served by the very thick layer of the white substance of Schwann, and in that part of the nerve only which lies between its central and peripheral distribution? Why do we find, moreover, that this investment is invariably so much thicker where a number of nerves run for a long distance parallel to one another than where they cross one another at considerable angles?

250. Experimental investigation inconclusive.—

Most of those who have taken up the subject of nerve action from the experimental side, appear to have had a very imperfect acquaintance with the structure of the tissue upon which they were experimenting. The transmission of electric currents through the nerves after the death of a recently killed animal, is a very rough operation, and indeed very different in many particulars from the transmission of the natural currents, whatever may be their nature, along the axis cylinder, while it remains in connexion with its central cells during the life of the animal.

If we were to take a bundle of several marine cables, and smear the gutta-percha investment carelessly over the cut ends of the copper wire cores, at a distant part of the circuit, and then transmit a most powerful current through the deranged wires, we should not find the needles acting as they did when very delicate currents were made to traverse an individual wire. The differences observed might induce some to conclude that the current by which the instrument was influenced in the normal state, was totally distinct in its nature from that much more powerful current which gave rise to the much greater but irregular and unmeaning disturbances. This reasoning is applicable to the experiments in which strong electric currents have been transmitted along compound damaged nerve trunks.

251. Fallacy of the argument based upon the excitability of nerve fibres.—It has been said that the fact that nerve loses its excitability without losing its power of conducting electricity, is a fatal objection to the doctrine that the nerve current transmitted during life is of the nature of electricity. But many things seem to have been entirely overlooked by those who urge this argument with so much confidence. Is it not obvious that soon after death, the bioplasm which is instrumental during its life in maintaining an equable flow of nutrient fluid through the tissue adjacent to

it, must cease to effect this important change? Is it not certain that in consequence the axis cylinder of a nerve-fibre must be much changed, and especially at the peripheral distribution of the fibres where they are very delicate and ramify naked upon the muscular tissue? No wonder then that the muscles fail to respond to the stimulus as before. This fact is attributed to the nerve having lost its "excitability," but is it not more probable that the true explanation of the fact is, that in consequence of the change in the constitution of the nerve-fibre, resulting from the cessation of the currents of fluid through it consequent upon the death of the bioplasm, it fails to conduct the electrical current as it did when in a state of integrity? So far, therefore, from the above fact being an argument against the idea that nerve force is really electricity, it actually affords support to this view.

The power of causing the muscles to contract when the nerve is irritated, is lost sooner if the nerve be irritated than if it be left at rest. It is increased by heat and decreased by cold. When the nerve is "irritated" the operation is such as would be certain to alter any structure so delicate as the peripheral ramifications of nerves and impair or destroy their conducting power. Dr. Rutherford has remarked that the nerves of a weak animal conduct faster than those of a strong one. "The velocity is so great in this case that it may be scarcely measurable," a fact which, perhaps, may depend upon the circumstance that the conducting tissue is more moist. In weak animals the masses of bioplasm are much more abundant than in strong ones and the tissues contain a large quantity of fluid. The axis cylinder participates in this change, and in this way the remarkable irritability manifested may be accounted for.

Again, it has been argued that because the irritability of a nerve can be destroyed by the electrical

current, nerve cannot be a mere conductor of electricity, and that nerves after death are as good *conductors* of electricity as during life, and that frozen nerves conduct electricity, though they will not transmit nervous energy. These objections are considered by many to be fatal to the idea that nerve force is after all only electricity. But a little consideration on the part of those who argue thus, would have convinced them that the facts above referred to are as easily explained upon the electrical as upon any other hypothesis of nerve action.

Little can be gained from the argument that a bit of nerve that has long been dead conducts electricity as well as a nerve just removed from a living animal; for neither are much better or worse conductors than some other tissues of the body. We must remember that in nature the thing that actually transmits the nerve current is the axis cylinder alone, but that in our experiments, we send comparatively strong currents through the white substance of Schwann and axis cylinders indiscriminately. The current deranges the axis cylinders, and of course seriously damages the delicate distal ramifications of the nerve fibres, § 230. No one who has seen and studied the ultimate ramifications of nerve fibres in tissues, will suppose for a moment that anything conclusive will be learnt concerning the action of nerves, by sending powerful electrical currents through damaged nerve trunks.

252. Fallacy of the argument deduced from the rate at which the nerve-current travels.—It has been said that the difference in the rate at which nerve energy and electricity travel, is enough to convince us that these two currents are not of the same nature. But the comparison as it has been instituted is not fair. Electricity as it travels along *a copper wire* has been contrasted with nerve energy (electricity) as it travels along a *moist fibrous cord.* No wonder that the rate at which the nerve current travels along the

nerves should be very slow as contrasted with the rate at which electricity traverses a copper wire, but such a fact by no means proves that nerve energy and electricity are very different. The nerve current, it has been proved, traverses not more than from 100 to 300 feet in a second of time, while electricity, it is known, travels at the rate of many thousands of miles in a second. The deduction is, however, defective, and in many ways. I would remark—

1. A comparison is made between the passage of the nerve current along a moist tissue and the passage of electricity along a copper wire.

2. It must be borne in mind that it is certain that if the nerve current were electricity, it would travel very slowly along such a structure as the axis cylinder.

3. The rate at which a single axis cylinder transmits a current of electricity has not yet been ascertained, but this is exactly the information we need before we can arrive at a correct conclusion.

4. The rate at which electricity travels through such a moist tissue as the axis cylinder has to be ascertained and compared with the rate at which nerve energy is known to travel.

I will only remark further that no one has yet succeeded in showing that the nerve current is *not* electricity, while a great number of well-ascertained facts, especially those known in connection with the electrical organs of certain of the lower animals, are strongly in favour of this inference.

253. Of the action of the bioplasm of nerve-fibres. —But if conclusive proof had been afforded that the nerve current was electricity, we should not even in that case have ascertained the whole truth, and, indeed, should have advanced but a little way towards a true explanation of nerve phenomena. *Action* and *work* are due not to force alone, but to the machinery by which the force is conditioned, and this is deter-

mined in nerve organs by the arrangement of the fibres and centres—in short, by the form or structure of the nerve apparatus. And this form and structure are the result of a long series of changes of the most complex character, which cannot be fully explained in the present state of our knowledge, but can be proved to be dependent upon the bioplasm. And since it has been shown that the nervous system at an early period consists entirely of bioplasm, and that in the fully developed state there is much bioplasm associated with those parts of it which we know to be most active, especially all nerve centres and all peripheral nerve organs, it is obvious that we cannot advance one step towards a true explanation of the phenomena until we have determined the exact nature of the changes which occur in this bioplasm.

A consideration of the facts renders it probable that the nerve fibre in all cases transmits the nerve current as a conductor, and that pressure, &c., upon any part of its course will affect the rate of transmission of the current and the conducting property of the fibre, but it is almost certain that the current *actually originates in the bioplasm, or in the soft formed material on its surface.*

That the masses of bioplasm, which I have shown to be numerous in the fine nerve fibres of nerve organs, besides taking part in the formation of the fibres, are concerned in nervous action, appears therefore to me probable from the following facts:—

1. They are very numerous in the peripheral ramifications of all nerves.

2. All special peripheral nerve organs, as the retina, the expansions of the olfactory and auditory nerves, the papillæ of touch and taste, as well as the peripheral nervous expansions beneath sensitive mucous membranes, the skin, &c., are remarkable for the great number, and some of them for the large size, of the masses of bioplasm.

3. The proportion of bioplasm is always very great in nerve centres, which are the principal seats of development of the nerve current.

4. That where, as in the sensitive papilla upon the toe of the frog, the nerve organ is more acutely sensitive (or more active in any other way) at one part of the year than at others, its increased activity is associated with a great increase in the amount of the bioplasm.

5. The principal change which takes place in a texture which in health appears to be but slightly sensitive, and becomes eminently so when inflamed, as the peritoneum, is a very great increase of the bioplasm which it contains, and this often proceeds to such an extent that the ramifications of the nerves appear as lines of oval masses of bioplasm. In the case of a tissue which in the healthy state gives no evidence of sensation, but which becomes acutely painful when inflamed, the feeling of pain is associated with, and probably is due to an increase of the bioplasm of the nerves themselves as well as to the increase of the bioplasm of other tissues which would necessarily affect the nerves by the mere pressure exerted upon them by the augmented bulk of material.

In every nervous action bioplasm is concerned, and as the phenomena of bioplasm cannot be adequately accounted for by physics and chemistry, it follows that no nervous action can be attributed to physical and chemical change only.

234. Concerning the probable action of bioplasm of nerve.—I have already shown that in all bioplasm the operation of some force or power of a nature different from any form or mode of energy yet discovered must be admitted.* This unknown agency

* See "Protoplasm," "The Mystery of Life," "Life Theories and Religious Thought," "How to work with the Microscope," and papers published during the last twelve years.

acts upon the material particles of which every mass of bioplasm consists, and induces changes in them which can neither be explained nor imitated. Every attempt hitherto made to show relationship between inorganic force and living force has absolutely failed. That there is a connection is believed and has been asserted over and over again, but there is not the shadow of reason for accepting the dogma that has been promulgated. Men may be made to say that life is force, but no one has produced the slightest evidence for adopting such a belief. While, on the contrary, every fact of life which we are able to investigate, leads us to the conclusion that, whatever life may be, it cannot be ordinary energy, or any form or mode, or mood of ordinary energy of which physicists have as yet any cognizance or conception. No form or mode of energy is known to occasion phenomena at all resembling those which are the consequence of the influence of life or vital force upon matter. A review of the general facts of living beings is not favourable to the idea of the universality of physical action, while even the most ardent physicists have been forced to confess that they cannot explain *mental phenomena* in terms known to physics. But physicists are as much bound to confess that they are equally unable to explain the phenomena characteristic of any particle of living matter in nature.

Now the bioplasm of certain parts of the nervous system is influenced in a definite manner, so that certain changes result in the nerve mechanism with which it is closely related.

No doubt it is easy to explain by physics and chemistry the transmission of a current along the nerve fibres in many cases, especially, if it be admitted, and I am quite disposed to believe this to be the case, that the nerve current is electricity. The little bioplasts are, we will suppose, the batteries where chemical changes occur and electricity is generated. But then

we must bear in mind that the very nerves through which the current passes were produced by the bioplasm, and the bioplasm was instrumental in the arrangement of these nerves. The phenomena of the nervous system, the action of nerves, depend entirely upon the arrangement of the nerve fibres and the bioplasts. Although, therefore, the nerve current may be due to chemical change, and the arrangement of the nerves might be accounted for by physical actions, both series of phenomena are dependent upon antecedent operations, which must be at last referred to the direct influence exerted by the peculiar power which is associated with the matter of the bioplasm during its living state. The vital power of the bioplasm is the agency by which the positions of the molecules which at length constitute the "nerve fibres" and "nerve cells" is determined, and this also causes the particles of matter to assume relations of such a nature that by the mutual interaction of their material forces currents may be set free.

255. The vital power of the highest bioplasm.—In the highest bioplasm the vital power determines movements which by reacting upon a previously formed mechanism may give rise to the most complex phenomena. In the mental apparatus, the "will" is the "power" which determines the movements of the matter of the bioplasts taking part in the phenomena of mind. This is a *vital* action, the highest *vital* action with which we are acquainted, but clearly to be included in the same category as the *vital* actions which determine the active movement of the matter of the simplest forms of bioplasm, as that of an amœba, or a white blood-corpuscle, or other bioplast. The movements of this the highest form of bioplasm react upon a wonderfully elaborate apparatus, parts of which are in close relationship with the mental bioplasts. Changes excited in the apparatus are the immediate consequence of the vital movements. These last only are

truly mental, while the expression of thought is but a result of the influence of the mental vital action upon the mechanism concerned in expression, without which thought could not be rendered evident to another person. A great distinction must indeed be drawn between the *thought* and the *expression* of the thought.

From the foregoing observations the reader will be led to conclude that I regard a nervous apparatus as consisting essentially of fine fibres and masses of bioplasm, which form uninterrupted circuits. The fibres are continuous with the bioplasts, of which some are central, some peripheral, and grow from them. By chemical changes in the matter formed by the bioplasts electrical currents may be produced, and these traverse the fibres. The currents varying in intensity according to the changes in the nerve cells would be affected by pressure upon the nerve cords which transmit them. Currents emanating from bioplasts at one part of the circuit would influence the changes in the bioplasts in another part, and the last react upon the first.

The formation of the nerve fibres and cells—the construction of the nerve mechanism, must be referred to the properties or powers of the bioplasm which preceded its formation. The *action* of the mechanism may be said to be due directly to physical and chemical change, but the matter which is changed, it must be borne in mind, was formed by bioplasm, and owed its origin to bioplasm. The higher phenomena of the nervous system are probably due primarily to the movements of bioplasm by which some part of the nerve mechanism is acted upon. The movement of the bioplasm is *vital*, occurs only during life, and is due to vital power—which vital power of this, the highest form of bioplasm in nature, is in fact the living *I*.

Microscopical Specimens illustrating Lecture IX.

No.		No. of diameters magnified.
65.	Ultimate nerve fibres, cornea. The bioplasm of the nerve is distinct from that of the cornea.. ..	215
66.	Ultimate pale nerve fibres, with bioplasm; frog ..	215
67.	Fine nerve fibres with their bioplasts or nuclei; trunk of a nerve	215
68.	Bundles of nerve fibres and vessels; frog	130
69.	Nerve fibres and ganglion cells; frog	130
70.	Ganglia and nerve fibres, with small arteries; green tree frog	40
71.	Nerve fibres and arteries; green tree frog	40
72.	Nerve fibres and ganglion cells, green tree frog; a vessel crosses the specimen in the lower part ..	215
73.	Ganglion cell with straight and spiral nerve fibre; green tree frog	700
74.	Large caudate nerve cells in anterior cornu of grey matter; spinal cord	40
75.	Large caudate nerve cells; upper part of spinal cord; dog	130
76.	Caudate nerve cells, grey matter of brain; lamb ..	215
77.	,, ,, ,, dog	215
78.	,, ,, ,, cat	215
79.	,, ,, ,, human subject ..	215
80.	,, ,, girl, aged 16 ..	215
81.	,, ,, man, aged 60 ..	215

LECTURE X.

Of Muscular Tissue—Protoplasm of Muscle—Contractile and Vital Movements—Contraction of Muscle—Voluntary and Involuntary Muscle—Unstriped or Involuntary Muscle; from the Bladder; from Arteries—Structure—Striated or Striped Muscle—The bioplasm of Muscle—Formed material of Muscle—Sarcolemma—Development of Muscular Tissue—Changes occurring in old Muscular Tissue—Fatty Degeneration.

256. Peculiar property of muscle.—No phenomenon has been discovered in connection with the action of any of the tissues already considered, which at all resembles that which is the peculiar characteristic of muscle. In both muscle and nerve "molecular" changes, remarkable for their rapidity and repetition, take place, the exact nature of which is still doubtful. Although these tissues are associated and intimately related to one another, it is doubtful if the changes in muscle and nerve are of the same kind. If in nervous action there is an actual movement of the particles of matter entering into the formation of the nerve fibre, the movements are more subtle, and of a different character; nor are they evident like those which occur in all contractile tissues. The striking alterations which take place when the muscle, or part of it, passes from the state of rest into that of active contraction, can be seen and measured while under the microscope. An actual shortening can be observed to take place in each elementary portion of muscular tissue every time it contracts. What the muscle loses in length it gains in width, or nearly so,

for a little fluid is expressed from the substance of the contractile material during contraction, and taken up again as it returns to the previous quiescent condition. The constant repetition of similar changes is characteristic of contractile tissues.

The states of *rest*, of *partial contraction*, and *complete contraction*, are but different degrees of the selfsame process of shortening of a delicate fibre. This contractile fibre perhaps consists of a passive basic substance of a fibrous character, through which is diffused a soft material prone to move in directions at right angles to one another, according to the manner in which external forces operate upon it. The changing substance upon which the alteration depends can be expressed from the muscular tissue, and coagulates spontaneously like the fibrin of blood. Young muscles yield a larger proportion of this material than old ones, but I do not think that it is derived solely from the *bioplasm* of muscle.

257. "Protoplasm" of Muscle.—The contractile tissue of muscle has been considered to be a form of "protoplasm," and muscular contraction has been attributed to the "*contractile property*," supposed to be potentially resident in the original elements of which the fibrin or protein matter is composed, just as the fluid property of water is to be referred to the properties of its constituent gases! But protein is not contractile, nor is any variety of this passive substance endowed with such a property as that which is characteristic of muscular tissue. Moreover, the living matter of an amœba or white blood-corpuscle is further removed from protein than muscle itself. Albumen, fibrin, and a number of other things, result from the death of the living matter, but it would surely be deemed absurd to attribute the property of living matter to the properties of the elements of the materials resulting from its death, § 17. Nor has any one yet shown that the contractile material of

muscle is the same substance, or even closely allied to the matter constituting the moving matter of any form of bioplasm. The bioplasm (nucleus) of muscle, its movements during the formation of muscular tissue, and the tissue or formed material produced by it, are represented in Plate IV, fig. 3, page 217.

238. Contractility and vital movements.—The doctrine that living matter and the contracting material of muscle are composed of the same substance, in the present state of knowledge, is untenable, and any one who examines muscle contracting, and compares the action with that of the living matter of an amœba, a white blood-corpuscle or a pus-corpuscle undergoing its varied and very remarkable movements, will feel quite convinced that movements, differing from one another in so many respects, cannot be due to one and the same property; nor will those who have actually studied the phenomenon be inclined to class the latter, which have been shown to be *vital* movements, in the same category as movements referred to "contractility." It must be obvious to any one who considers the question, after having carefully observed the facts, that muscular contraction is a mere alternation of movement, limited in direction as well as regards the degree of change. On the other hand, a mass of bioplasm may move in any direction whatever, and there is no limit to its movements. So varied are the *vital movements* of living matter, that the same mass probably never twice in its life assumes the same form. Moreover, the living matter may move itself in its entirety from one place to another, while a portion of contractile tissue can only become shortened and lengthened, but it must remain in the same place. In the first case one portion may move *in advance of another portion*, and in any direction, while in the contractile tissue, although one part may move in a direct line to or from another part, it is not possible for any particle to get before, or place itself

in front of, another particle. A contractile tissue might be likened to a chain of beads, every bead being capable of becoming short and broad or long and narrow, but forced to retain, by reason of its connexions, its relative position with regard to every other bead. But the particles of a mass of living matter are not thus chained together. Each is free to move in any direction whatever, and the particles do not retain the same relative position for a moment. The movements of the muscular tissue, as regards direction, extent, and place, are limited, and are determined by external forces. The contractile cord may become shorter, causing its points of attachment to approximate, but it cannot move itself in its entirety. On the other hand, it is characteristic of living matter to move in any direction, and to pass from one place to another, according to the operation of forces acting from within the matter itself.

There is, therefore, no analogy between the movements of living bioplasm and those of contractile tissues formed from living bioplasm. These movements are essentially different from one another, and cannot be classed together. Moreover, living matter takes up pabulum, and changes this or some of its constituents into living matter like itself, but under no circumstances, actual or conceivable, can the *contractile tissue produce more contractile tissue like itself.*

259. Of studying the contraction of muscular tissue.—The phenomena of contractility can be studied more satisfactorily in the muscles of the common maggot or larva of the blow-fly than in those of any other animal I am acquainted with. The movements, which are very beautiful in these particular muscles, continue even in hot weather for ten minutes or a quarter of an hour after the muscles have been removed from the body of the recently killed animal. A specimen may be prepared and passed round the lecture-room. In the winter I have

known the contractions continue for upwards of half an hour. But the most beautiful and instructive method of examination is under the influence of polarized light, with a plate of selenite. When the ground is green, the waves of contraction which pass along each muscular fibre in various directions, are of a bright purple. In other parts of the field the complementary colours are reversed. There are few microscopic objects, that I am acquainted with, more beautiful than this. With the aid of very high powers, the actual change occurring in the contractile tissue as it passes from a state of relaxation to contraction, and from this to relaxation again, may be studied, and for many minutes at a time.

Muscular movements may also be observed in many of the insect larvæ, and, as suggested by Mr. Bowman, in the muscular tissue removed from the leg of a young crab. In cold weather muscular movements are never very vigorous, but they continue for a much longer time than during warm weather.

Sometimes muscles continue to contract for some days after an animal has been "killed." The muscles of cold-blooded vertebrata retain their contractility long after the brain has been destroyed or the head removed from the body, and insects may often be kept for days after apparent death has taken place, and yet retain a degree of muscular contraction. Mr. Holmes, of Horsham (in a letter to me in February, 1872), gives an interesting example in which muscular contractility remained in a drone-fly fifty-four hours after it had been decapitated and immersed in spirits of wine for three hours. Although so long an interval of time had elapsed sufficient contractility remained to permit the muscles to execute forty-two convulsive movements of the legs during thirty seconds.

The character of muscular movements has been fully

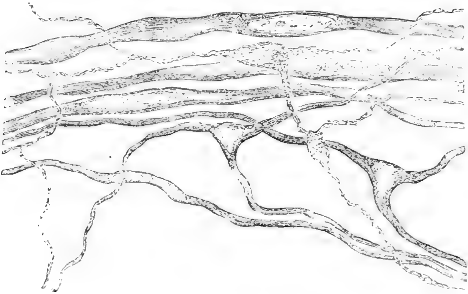
described by Mr. Bowman in his well-known paper (Phil. Trans., 1841). The reader is also referred to Mr. Bowman's article, "Muscular Motion," in Todd's Cyclopædia of Anatomy and Physiology.

260. Two kinds of muscle.—The contractile material of muscular tissue is arranged so as to form fibres, plates, cords, or bands, varying much in dimensions and somewhat in minute structure. By examination with the aid of high magnifying powers we are enabled to distinguish the different kinds of muscular tissue, which may be arranged in two classes according as the contractile tissue appears structureless, or exhibits an appearance of longitudinal striation, distinct transverse bars, striæ, or stripes. The fibres of the *voluntary* muscles (or those the movements of which can be either excited or controlled by volition), as well as the fibres of the heart, and some of those of the œsophagus, are *striped;* while all other muscles, including those of the alimentary canal, the uterus, and bladder, all of which are *involuntary*, are *unstriped.*

261. Unstriped muscle.—The unstriped muscular tissue may be studied in many organs of vertebrata, but the most favourable situation known to me, is the bladder of the frog. In the thinnest parts of this extremely delicate membrane the muscular fibres or fibre-cells form a single layer, and are often separated from one another, so that an individual elementary fibre may be followed from one end to the other. Bundles of these long spindled-shaped elementary parts are arranged around all the vessels, but in the intercapillary spaces are numerous separate fibres which cross each other at various angles, and are so arranged that when they contract, the area of the membrane is reduced in every direction. In the central part of each fibre or fibre-cell is the oval mass of bioplasm (nucleus), at either end of which new contractile material is produced as the fibre increases in length. From these points the muscular band

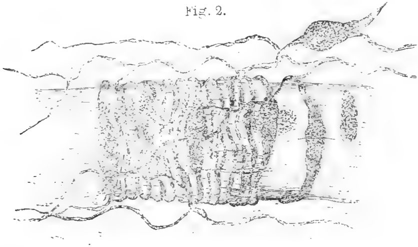
Plate V.—UNSTRIPED AND STRIPED MUSCLE.

Fig. 1.



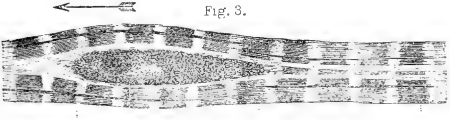
Portions of spindle-shaped and tricaudate muscular fibre-cells from the thin part of the bladder of the hyla or green tree frog. The fine branches of nerve are seen ramifying amongst the muscular fibres × 700.

Fig. 2.



Portion of very small artery showing muscular fibre cells and nerve fibres, ramifying in the areolar coat. Frog. × 700.

Fig. 3.



a *b* *c*

Bioplasm and formed material (contractile tissue) of striped muscle. The bioplasm is supposed to be moving in the direction of the arrow. At present it is between ***a*** and ***b***, but it was once between ***b*** and ***c***. As it has moved onwards, it has formed a filament of contractile tissue in its wake.

becomes narrower, and at either extremity tapers into a tendinous thread, which is inserted into, and is indeed continuous with, the connective tissue. The contractile matter itself appears perfectly smooth, and under the highest powers exhibits a very faint striation in the longitudinal direction. In some of my specimens a fibre has been preserved in a state of contraction, when undulating swellings may be observed at short intervals, giving to the fibre a beaded appearance. (See the uppermost fibre in Fig. 1, plate V, page 217.) If the bladder be examined at different ages, the mode of growth of the muscular fibre cells in length and breadth will be understood, and in the bladder that has grown old it will be found that many of the cells have degenerated into connective tissue. In the adult bladder even, young muscular fibre cells may be found, and the conversion of the contractile material into fibrous tissue demonstrated.

262. Muscular fibre-cells with three or more fibres.—The most remarkable muscular fibres are those which have three, four, or even five tail-like processes extending from the central triangular, quadrangular, or pentangular mass of bioplasm. These are found in considerable number in the thinnest parts of the bladder of the frog, hyla, and newt, which correspond to the intercapillary spaces.

From the uterus of the white mouse some beautifully delicate spindle-shaped muscular fibre-cells may be obtained. The muscular coat of the stomach and small intestine of the same animal will also furnish the observer with good specimens of muscular fibres. In order to isolate these bodies, soaking in dilute nitric acid, tearing with needles, and other chemical and mechanical expedients have been recommended; but in the thin membrane which constitutes the frog's bladder these cells are isolated ready for observation. In the spaces between the vessels in specimens prepared according to the plan I have recommended,

numerous single cells may be seen and followed from one end to the other without difficulty. (Fig. 1, plate V, page 217.)

263. Muscular fibre-cells of the arteries.—But of all the forms of unstriped muscle, that which encircles the small arteries and ramifies over the coats of the veins, is, in many respects, the most interesting, for by its influence the calibre of the small vessels is altered, and the amount of blood to flow through the capillaries of a particular tissue in a given time determined, and its movement regulated. If the pressure employed in injecting the vessels artificially be very gradually increased, the smaller arterial tubes may be distended, so as to separate very slightly from one another the encircling muscular fibre cells; and in fortunate specimens prepared in glycerine, I have succeeded in gently tearing asunder the vessel, so as to display not only each individual muscular fibre cell with its bioplasm, but the nerve fibres distributed to it. A good example of this is seen in Fig. 2, plate V, page 217, and another in Fig. 4, plate XVI, § 12. The distribution of the nerves to these muscular fibres, and the arrangement of the mechanism by which the blood flow is varied, will, however, be further considered in my last lecture.

264. Striated or striped muscle.—The fibres of *voluntary* or *striped muscle* differ from those of the involuntary muscular tissue, in many particulars. They exhibit transverse as well as longitudinal markings, and easily cleave or are split up in these directions. The fibres vary very much in size and general arrangement in different animals, and in different muscles of the same animal. The elementary fibres of one muscle may be less than the $\frac{1}{3000}$th of an inch in width, while those of other muscles attain a diameter of as much as the $\frac{1}{50}$th of an inch. The elementary fibres of insect muscle exhibit the general

characters of this beautiful texture very distinctly, and specimens may be prepared without difficulty.

Striped or voluntary muscle may consist of wide or narrow fibres arranged perfectly parallel to one another, or the muscle may consist of two or more layers, the constituent fibres of which cross one another at right angles. In some cases the fibres are very irregularly arranged, and cross in various directions. Striped muscular tissue also exists in the form of conical fibres which gradually taper towards one extremity into a tendon, Plate XIV, page 271. The fibre in some cases divides and subdivides almost like the branches of a tree, in which case it is termed branching muscle. This is found in the frog's tongue, page 271. Lastly, striped muscular tissue may be arranged so as to form a net-work, a beautiful example of which exists in the auricle of the frog's heart.

Structure of an elementary fibre or fasciculus.—A good general idea of the structure of an elementary fibre of striped muscle will be formed if a specimen from the large water-beetle, *Dytiscus marginalis*, be carefully examined. Here the transverse markings are seen upon a considerable scale, and the elementary fibre is very large, Fig. 3, plate VI, see also Fig. 1. The contractile tissue has ruptured within the sarcolemma, and has cleaved transversely in several places. Two of Bowman's discs are detached from the rest of the contractile tissue, and lie free in the tube of the sarcolemma. The masses of bioplasm concerned in their formation are seen in the centre of the disc, *a*. The contractile tissue, with the delicate closed tube of sarcolemma forming its outer limit, constitutes an elementary fibre or fasciculus of striped or voluntary muscle. The contractile material which occupies the tube of the sarcolemma may be split up in two directions—*longitudinally* into *fibrillæ*, and *transversely* into *disks*—as was first demonstrated by Bowman.

In one specimen from the frog the contractile tissue

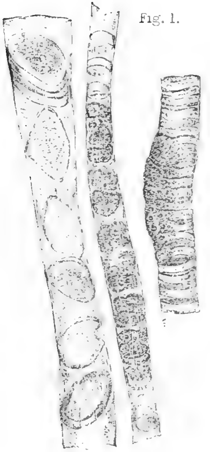
is fractured transversely. Shortly before death the spasm of the muscle was so violent as to cause its rupture, and portions of the broken and contracted sarcous matter may be seen within the sarcolemma of every fibre of the muscle. A corresponding appearance is often seen in the muscles of persons who have died of tetanus.

265. The bioplasm of muscle.—The proportion of bioplasm or germinal matter to the formed material in fully formed muscular tissue is considerably less than in many other textures—a fact which is conclusive in favour of the view that muscle is not a rapidly changing tissue. Many years ago I taught, contrary to the chemical doctrine then in high favour, that muscular contraction was not to be explained by the disintegration and oxidation of the tissue itself; and I also showed that the conjecture advanced from the chemical side, namely, that muscular tissue was removed and replaced within a very short period of time, was not supported by facts. Those who advocated this strange notion did not attempt to show *how* so large a quantity of a highly elaborate tissue was removed and replaced. Had they inquired, they would soon have been convinced that no means existed by which the necessary amount of tissue could be replaced or developed within the time allowed. Further observation has, however, satisfied chemists that the conclusion was erroneous, and now a very different doctrine prevails, which, however, if not equally untenable, is almost as improbable as that which it replaces.

The larger size and greater number of the masses of bioplasm in proportion to the amount of tissue in young muscular fibres, as compared with fully developed ones, is well seen in some of my specimens, particularly No. 105, in which two elementary muscular fibres—one from a pig at birth, and the other from a pig three months old—have been mounted together

PLATE VI.—STRIPED MUSCLE.

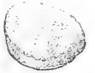
Fig. 1.



a *b* *c*

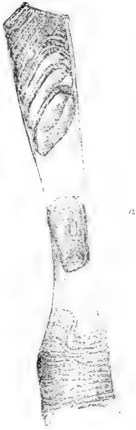
Developing muscular fibres from the young newt showing contractile tissue split into Bowman's discs within the sarcolemma *a* *b* [illegible]oplasm be[illegible] [illegible]verted into muscular tissue. × [illegible]

Fig. 2.



Separated disc from specimen in [illegible]

Fig. 3.



Elementary muscular fibre Dytiscus Marginalis, showing sarcolemma and contractile tissue split into discs The [illegible] plast is in the centre of each disc, as seen at *a*. × [illegible]0.

Fig. 4.

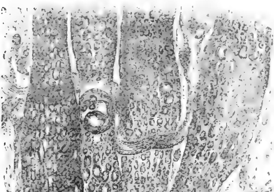
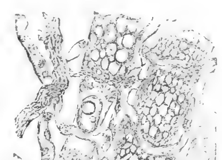


Fig. 5.



Striped muscle in a state of fatty degeneration from prolonged inaction, Of the sarcous tissue only a trace remains at *a*, fig. 5 In this last figure vessels and nerve fibres are also represented.

for comparison. Such a specimen will, I think, convince any one that the masses of bioplasm are concerned in the production of the contractile material of muscle. By the accurate comparison of carefully prepared specimens of this kind, we are even able to form a notion of the rate of the growth, and to prove that muscular tissue is not formed very quickly, or its elements removed and replaced within a short period of time. It is not improbable that in the higher vertebrata the very same elementary fibres continue in action for years. The idea that the contractile material is removed and replaced by new tissue within a few days or weeks is untenable, and would not have been suggested by any one who had taken the pains to acquaint himself with well-known facts, unless he or had determined to ignore the results of anatomical observation altogether.

From what I have already stated, the reader will have inferred that the position of the masses of bioplasm varies very much in different kinds of striped muscle. In some forms we find a row of nearly spherical bioplasts in the very centre of the elementary fasciculus of contractile tissue: in others an oval mass is seen at the side of a very long narrow fibre consisting of very few fibrillæ; and in many of the muscular fibres of various classes of vertebrata numerous oval masses are situated at short distances, and alternating with one another throughout the whole extent of the tissue within the sarcolemma. This variation in position, and the difference observed in the relative proportion of bioplasm and contractile tissue in muscles which act in the same manner, lead me to infer that the bioplasm is not immediately concerned in muscular contraction.

The living matter is instrumental in the formation of the original contractile tissue, and in the production of new tissue to take the place of that which is slowly removed, or to be added to that which exists

in cases in which the muscle has to perform increased work. The living matter also determines currents of fluids towards it, and by its agency the contractile tissue is permeated in every part by fresh portions of fluid which transudes through the vascular walls from the blood.

It is very important to consider the exact relation of the bioplasm to the contractile material of muscle. From young growing muscle taken quite fresh and carefully prepared with the carmine fluid and mounted in glycerine, bioplasm may be frequently detached with a portion of the sarcous tissue still adhering to it. If such a specimen be examined with a high power, it will be found that the bioplasm passes into soft granular material, and that this last is continuous with the contractile tissue of the muscle. The soft delicate substance which intervenes between the bioplasm and the contractile tissue consists of imperfectly developed formed material. This, like all the contractile tissue already formed, was once in the state of bioplasm. As in other cases, while the formation of tissue is proceeding, we are able to point out the *living, growing, moving bioplasm, the imperfectly developed formed material, and the fully formed tissue.*

266. Formed material of muscle non-living.—The opinion is generally entertained that the contractile material of muscle is in its nature different from the formed material of other tissues, but from what has been stated it will be seen that there is good reason for regarding the contractile tissue as a *formed* but *non-living* substance possessing remarkable properties, but not manifesting any of those phenomena which are peculiar to matter in a *living state.* While every one will agree with me in regarding the tissue of the fully formed hair, nail, and epidermis as non-living; and some will not strongly object to the same view being applied to the formed material of bone, cartilage, and white and yellow fibrous tissue; few will

be disposed to go the length of placing in the same category as the above passive tissues, muscle and nerve-fibre. To these last textures mysterious *vital* properties are assigned, and, strange to say, even by those who entertain the strongest opinions concerning the physical character of *all* the phenomena of living beings. Although neither muscular nor nerve tissue can *produce new texture*—although each exhibits well-marked *structure*, and is destitute of every attribute of living matter, it is maintained that muscular contraction and the transmission of a current along a nerve-fibre are *vital* phenomena.

Some, perhaps, may incline to the opinion that bioplasm exists diffused through the formed material of these textures, and that to it their wonderful properties are entirely due. It is therefore desirable in this place to consider the possibility of such an arrangement in the case of muscle. The structure of unstriped muscle is smooth, or very slightly fibrous, but exhibits no indications of containing bioplasm in its substance. The tissue is not tinged with the carmine fluid. It possesses all the general characters of formed material, and its relation to the bioplasm is the same as that of the formed material of other tissues. The evidence is therefore against such a view as regards unstriped muscle. Neither is it probable that in each sarcous particle of striped muscle there is a minute portion of bioplasm, because, *in the first place*, the living matter cannot be detected at an early period of the development of muscle; *secondly*, in inflammation and in other morbid conditions in which the masses of bioplasm of tissues are much increased in size, no change is seen in the sarcous particles themselves; *thirdly*, the lines of sarcous particles correspond with the wavy bands of the fibrous tissue of tendon, which unquestionably consist of formed material only; *and lastly*, since the very transparent contracting tissues of some of the lower animals do

not contain bioplasm in their ultimate fibrillæ, there is good reason for concluding that there is no living matter in the substance of the higher forms of contractile tissue. The phenomenon of contractility characteristic of this class of tissues is therefore probably due to changes in non-living formed material only, and is not in any way dependent for its manifestation upon bioplasm.

267. Sarcolemma.—The sarcolemma of muscle appears as a transparent tube composed of very delicate membrane, figs. 1, 3, Pl. VI, p. 222, which is thick in old and fully formed muscles, but very thin in young muscular fibres, while during development, and in the case of some forms of adult muscular tissue (heart, tongue), no sarcolemma can be detected. Upon its outer surface the sarcolemma is connected with the delicate intermuscular connective tissue, with capillary vessels and nerve fibres, and in insects the trachæ are adherent to it, and in some cases are almost embedded in its substance. The greater number of the masses of bioplasm on the surface of the sarcolemma of the muscles of vertebrata are those of the numerous nerves and capillary vessels distributed to the elementary fibre. These are extremely numerous upon the sarcolemma of the elementary muscular fibres of small rodents, as the mouse, but they are seen in connexion with the sarcolemma of almost all muscles. The masses of bioplasm, which I have proved belong to capillary vessels and nerves distributed to this tissue, have been generally regarded as "connective tissue corpuscles," and the same erroneous conclusion has been arrived at concerning the masses of bioplasm belonging to vessels and nerves distributed to many other tissues, and essential to their formation, growth, and action.

The sarcolemma of the muscles of insects is a very complex structure, in which air tubes or trachæ and excessively minute nerve fibres ramify in immense

numbers. See my paper in the "Transactions of the Microscopical Society, 1864."

268. Of the junction of muscle with tendon.—If an elementary muscular fibre attached to its tendon, taken from a properly prepared specimen, be examined, it will be seen that the formed material of the muscle is directly continuous with that of the tendon, and that the oval masses of bioplasm bear to the formed material of the two textures respectively a similar relation. In specimen 96 these points are well illustrated, and the observer who considers carefully the facts demonstrated in specimen 99 of developing muscle, in 105 of young and fully formed muscle, and in 104 showing the junction between muscle and tendon, will, I think, feel convinced that the formed material of muscle is produced by the bioplasm, and that for its development and growth muscle is dependent entirely upon this living substance, which in the adult exists in very small proportion.

269. Development of muscular tissue.—At an early period of development the masses of bioplasm which take part in the development of striped muscle divide and subdivide so as to form rows. The delicate formed material which is produced upon the outer surface of these gradually acquires consistence and exhibits contractility. At first there are indications of faint longitudinal striations, but transverse markings become visible as soon as the tube of contractile tissue thus produced acquires the thickness of about the $\frac{1}{5000}$th or $\frac{1}{1000}$th of an inch. A beautiful specimen of developing muscular fibre, in which all these points are clearly demonstrated, is seen in prep. 102, from the calf at an early period of development. These elementary fibres, however, only serve a temporary purpose, and gradually give place to elementary fibres of a different structure. The fully formed muscular fibres of some insects exhibit precisely the

characters of the embryonic fibres of the higher vertebrata. Some of the muscular fibres of the adult frog and hyla have masses of bioplasm in the centre of the elementary fibre, as just described; so also have the muscular fibres of the heart of the human subject. The fibre increases in diameter by the formation of new contractile tissue within, which is formed upon the surface of the bioplasm, and the contractile tissue which had been produced previously is pushed outwards. Many muscular fibres—as, for instance, those of the delicate muscles of the eye of the smallest animals—exist at an early period as spindle-shaped bodies, which taper at either extremity into the tendon. The large mass of bioplasm is in the centre, and is surrounded by formed material, which gradually accumulates upon its surface and at its two extremities. Thus the fibre increases in thickness and length.

In the connective tissue of the nose of the nearly full-grown mole (prep. 103) the development of muscular fibre may be well studied, for in this situation are numerous bundles of very narrow, but distinctly transversely striated, muscular fibres, which taper at either extremity into tendons of great length which pass into the connective tissue.

In most of the permanent elementary muscular fibres of the higher vertebrate animals the masses of bioplasm are seen at intervals embedded in the contractile tissue, and disposed in much the same manner as the masses of bioplasm of tendon. In exceedingly fine fibres, an oval mass of bioplasm is often present upon one side only. In fibres of about the $\frac{1}{6000}$th of an inch in diameter, and apparently composed of only a very few fibrillæ, I have seen the oval mass of bioplasm situated a short distance from the side of the contractile tissue, with which it was connected by a small quantity of exceedingly delicate granular matter, exhibiting here and there indications of

transverse markings continuous with the transverse striæ of the muscle, fig. 1 c, Pl. VI, page 222. This delicate material was no doubt contractile sarcous matter imperfectly formed, which was gradually becoming condensed and assuming the characters and properties of the adjacent contractile tissue with which it was continuous; and I was led to conclude that, during the formation of the muscle, the oval mass of bioplasm moved parallel with the fibre, giving rise to the new tissue as it passed along, fig. 3, Pl. V, page 217. Many appearances afterwards observed confirmed this view. In the ordinary muscular fibres, as those of the frog, which are well adapted for observation, the oval nuclei in different parts of the fibre move upwards or downwards between several fibrillæ, and thus form new muscular tissue in every part of the substance of these large elementary fibres.

270. Changes occurring in old muscular tissues. Fibrous degeneration of muscle.—In old muscular tissue the proportion of bioplasm to the formed material is much reduced, and in some cases the muscular fibre appears to be destitute of bioplasm altogether. It nevertheless retains its contractile power unimpaired.

The proportion of tendon in connection with the muscular tissue, as well as the thickness of the sarcolemma, and the quantity of connective tissue, gradually increases as age advances; and in old age much of the muscular tissue is replaced by fibrous material. The contractile material of the muscle has *degenerated* (?) into fibrous tissue. In this process the soft contractile matter, which, as Kühne has shown, is fluid or semi-fluid, is absorbed, while an indistinctly fibrous basis substance remains. A similar change takes place after the contractility of muscle has for some time been impaired, as results from many forms of nerve paralysis; and when the central nerve disease progresses very slowly, a very great extent of mus-

cular tissue may pass into a state of fibrous degeneration.

In unstriped muscle a corresponding change is noticed as the fibres advance in age. The young fibre-cells consist almost wholly of contractile matter, but the extremities which are attached to connective tissue become gradually converted into fibrous material, and the change continues until the entire fibre-cell may be thus replaced, and is at last represented by a passive fibre of connective tissue.

271. Fatty degeneration.—In this morbid condition the contractile material in great part disappears, and in its place oil granules and globules are found. Fatty degeneration does not appear to be a consequence of nerve paralysis, at least in the greater number of instances. It runs its course in a shorter period of time than the fibrous degeneration. It occurs in unstriped muscle as well as in the striped fibre, and can always be observed in the altered muscular fibres of the uterus after parturition, and in the tissues near the margin of the placenta towards the end of the period of gestation. Fatty degeneration often affects a great number of tissues in the same individual. Nerves at the periphery and centre, ganglion cells, capillaries, arteries, veins, connective tissue, epithelium, cartilage, and even bone are not unfrequently affected by it, as well as every kind of muscular tissue. In many cases the fatty matter is first seen near the bioplasm, and results from changes taking place in the imperfectly developed formed material, and in the bioplasm itself oil globules are not unfrequently found. It is probable that the morbid change is in some cases dependent upon prior alterations in the composition of the blood, which are themselves the consequence of improper assimilation, or of the introduction into the organism of more food than can be properly assimilated; while in others it seems to be due rather to some unusual changes in

the bioplasm which depend upon an irregularity in the order of occurrence of the developmental phenomena.

In some pathological alterations an adventitious texture is formed outside a vessel by the multiplication of the masses of bioplasm of the tissue itself, as well as of the corpuscles resulting from the growth and detachment of buds or offsets from the white blood-corpuscles which have passed through the capillary walls with serous fluid (exudation). Collections of bioplasm are thus formed which give rise to alterations in the neighbouring tissue. An elastic transparent tissue, such as that of the fibrous coat of an artery, would lose its elasticity, and, in consequence, become friable and rotten. Gradually the bioplasm itself undergoes change, and at last dies. Fatty matter, cholesterin, and earthy phosphates are among the resulting products, and these remain outside or amongst the tissue of the vessel, interfering with the due performance of its function.

Fatty degeneration takes place in muscles that have remained for some time out of use, and in many of the lower animals it may be induced simply by keeping them in acid for some time. A beautiful example is represented in Pl. VI, figs. 4, 5, p. 222. The specimen of which this is a copy was taken from the abdominal muscle of a little hyla, or green tree frog, that had been kept many months in confinement. Not an indication of contractile tissue remains. The whole contents of the sarcolemma have disappeared, and fat globules are seen to be substituted for them. The capillary vessels were still pervious, and blood was distributed to the muscle during life, fig. 5, Pl. VI, p. 222. It is clear, therefore, that the fatty change is not due solely to insufficient supply of nutrient pabulum but depends upon other circumstances.

List of Microscopical Specimens illustrating Lecture X.

No.		No. of diameters magnified.
82.	Transverse section of muscular tissue of gizzard of bird; showing great regularity of the arrangement of the muscular bundles which have been divided transversely..	40
83.	Unstriped muscle, arranged in bands; intestine, frog	130
84.	Thin membrane; showing bands of unstriped muscular fibres with vessels (injected blue). Frog. Numerous masses of bioplasm in connexion with all the tissues	20
85.	Thin membrane, showing bands of unstriped muscular fibres, with numerous masses of bioplasm. Frog..	130
86.	Thin membrane, showing unstriped muscular fibre cells. Many of the masses of bioplasm are *triangular*, and some *quadrangular*, with muscular fibre radiating from each angle. Frog	215
87.	Unstriped muscular fibre cells, showing bioplasm and termination of fibres of unstriped muscle in connective tissue	215
88.	Unstriped muscular fibre cells, with vessels. White mouse	215
89.	Artery, showing unstriped muscular fibre cells encircling it, and nerve fibres. Chameleon ..	40
90.	Small arteries; pia mater brain, showing unstriped muscular fibre cells encircling them	130
91.	Arteries and vein, with numerous small branches; a bundle of fine nerve fibres is seen to the right of the artery	40
92.	Triangular muscular fibre cells from the aorta of the human subject. These much resemble some of the muscular fibre cells of the frog's bladder described in prep. 86	215
93.	Small artery, frog; showing muscular fibre cells encircling it, with numerous nerve fibres ramifying outside the muscular coat	215
94.	Small arteries with muscular fibre cells; membrane of brain at an early period of development ..	215
95.	Artery torn lengthwise, showing individual muscular fibre cells, with their masses of bioplasm ..	215
96.	Elementary fibres of striped muscle with vessels, newt. Observe the masses of bioplasm	40

No.		No. of diameters magnified.
97.	Elementary muscular fibres of striped muscle, newt; showing transverse striæ and masses of bioplasm	215
98.	Elementary fibres of striped muscle; pig ..	215
99.	Large and small elementary muscular fibres, frog; showing numerous masses of bioplasm	215
100.	Elementary muscular fibre, water-beetle; showing "discs" broken off within sarcolemma and masses of bioplasm in the *centre* of the muscular discs ..	215
101.	Extremely fine muscular fibres, showing transverse markings and bioplasm. Green tree frog ..	215
102.	Striped muscular fibres of calf at a very early period of development, showing large masses of bioplasm in centre of each fibre, as in insect muscle	215
103.	Very fine striped muscular fibres tapering into delicate fibres of connective tissue. Nose of the mole	215
104.	Connexion between striped muscle and tendon. Chameleon	215
105.	Muscular fibres of pig, at different ages. The fibres to the left are from the pig at birth, and those to the right from a pig three months old. In this short time each elementary fibre has increased to more than twelve times its bulk, and it will be observed that the amount of bioplasm corresponding to a given quantity of tissue is much greater in the youngest muscle	100
106.	Muscular fibres of heart of very fat pig, showing adipose tissue between them	130
107.	Striped muscular fibres in a state of fatty degeneration	215
108.	Striped muscle. Hyla. Showing contractile material fractured within the tube of sarcolemma ..	130
109.	Elementary fibres of hyla, or green tree frog, in an extreme state of fatty degeneration from a muscle which had long been inactive	220

LECTURE XI.

Distribution of Nerves to Muscular Tissue, and of the finest ramifications of Motor Nerves—Of the Nerves of Unstriped Muscle—Of the Nerves of Striped Muscle—Of the Tubular Nerve Fibres and of the Nerve Sheath—Ultimate Nerve-Fibres of Muscle—Memoirs on the Termination of Nerves in Muscle—Breast Muscle of the Frog—Nerves to the Muscles of the Hyla—Articulata—Of the Nerve-Tufts, Nerve-Eminences, or Nerven Hügel—Distribution of Nerves to other Forms of Striped Muscle, the Tongue, Heart, and Lymphatic Hearts—Of the Finest Fibres that influence the Muscle—Reply to Criticism.

Distribution of Nerves to Involuntary Muscle.

272. Distribution of nerves to the muscular fibres and other tissues in the bladder of the frog.—For the demonstration of the ultimate arrangement of the most minute nerve-fibres, there are very few textures which possess so many advantages as the bladder of the frog. It is so thin and transparent, that it may be regarded as a natural dissection and thinning-out of some of the most delicate tissues. The unstriped muscular fibres of this organ are extremely fine, and in many places are well separated from one another, so that fine nerve-fibres can be very distinctly seen in the intervals between them. Fig. 1, Plate V, page 217.

With regard to the presence of nerve-fibres in involuntary muscle generally, I would remark that I have demonstrated fine nerve-fibres in so many different cases, that it is more in accordance with the

positive knowledge already gained to infer that they exist in relation with every form of this texture, even in cases in which we may still fail to demonstrate them, than to infer they are absent simply because we have failed to render them distinct. And as I have detected nerves in every form of contractile tissue that I have examined, I think it right to conclude that contractile textures are invariably associated with nerves.*

The bundles of dark-bordered fibres which may be traced to the posterior part of the frog's bladder divide and subdivide freely, spreading out in the form of a lax network. The fibres may be followed for some distance, and many may be traced to their ultimate distribution in the thin tissue of the bladder. Over a great part of the frog's bladder, however, no dark-bordered fibres or bundles of moderately coarse fibres can be detected; yet the organ is in every part very freely supplied with nerves.

Bundles of excessively fine fibres, first described by me,† may be traced running parallel with many of the small arteries, and may be seen to divide and subdivide into finer bundles, which at length form a plexiform network. Here and there is seen a plexus composed of multitudes of very fine fibres, from which small bundles of fine fibres diverge in different directions. That very many of these fine fibres come from the numerous ganglion-cells found in connexion with the nerve-trunks there is no doubt; and it is equally certain that many also result from the divi-

* By contractile tissue I mean a tissue in which simple movements like shortening and lengthening alternate with one another, each movement being a mere repetition of the first movement that occurred when the *formation* of the contractile tissue was complete. See page 214.

† "On very fine Nerve-fibres in Fibrous Tissues, and on Trunks composed of very fine Fibres alone." (Archives of Medicine, vol. iv.) See also paper in Phil. Trans., June, 1862.

sion and subdivision of dark-bordered fibres. But whether the large dark-bordered fibres seen in the nerve-trunks pass directly to their distribution in the bladder, or in the first place become connected with ganglion-cells, it is difficult to decide with absolute certainty; I have, however, traced several of the large dark-bordered fibres directly from the trunks to their distribution, but even in these instances I am not prepared to assert that no branches pass to the ganglion-cells. My impression is that many of the fibres do so, but that some pass to their distribution without being connected with ganglion-cells. I think it probable that, of the fibres resulting from the division of a dark-bordered fibre derived from the spinal cord, some may become connected with the ganglion-cells above referred to, while others pass to their distribution in the bladder without being connected with these cells.

In the very thin membrane of which the walls of the frog's bladder are composed we may follow out the distribution of nerves—*a*, to the muscular tissue, *b*, to the surface of the mucous membrane, *c*, to the vessels, and *d*, to the connective tissue. There is a network ramifying on the outer surface, from which fibres pass to supply all the tissues of the bladder.

The muscular fibre-cells of the bladder itself and of the small arteries are crossed sometimes in two or three places by very fine nerve-fibres; and not unfrequently the nerve-fibre runs parallel with the muscular fibre-cell for some distance. Fig. 1, Pl. V, p. 217.

Some of the most recent drawings of this form of muscular tissue and the supposed arrangement of its nerves are very defective. J. Arnold, in his article on organic muscle in Stricker's "Anatomy," has given some not very satisfactory drawings of the muscular tissue from the frog's bladder. His figures on page 142, are evidently taken from *bundles* of muscular fibres. The delicate cells, isolated ready for obser-

vation in the thinnest part of the membrane, would have afforded far better objects for study; but from his drawings it is doubtful if he has seen these. The fibre-cells in question would probably not be recognisable in his specimens. Had he seen them, he must have noticed the outlines of each individual muscular fibre-cell, and would have observed the nerve-fibres crossing and recrossing them at intervals; and I think he would have been convinced that the nerves passed over, under, and parallel with the muscular tissue, but did not penetrate into the contractile tissue or reach its nucleus.

These nerve-fibres are extremely fine, and require very high powers for their demonstration. They are certainly not connected in any way either with the nucleus or with the contractile tissue of the muscular fibre. They cross the fibre either obliquely or at right angles; and oftentimes a nerve-fibre runs for some distance parallel with the muscular fibre. The influence, therefore, exerted by the nerve-fibre cannot depend upon any continuity of texture between it and the contractile tissue, but is doubtless due to the passage of a current through the nerve, which determines a temporary alteration in the relations to one another of the particles of which the contractile tissue consists.

Upon the external surface of the lung of the frog muscular fibre-cells exist in small number, and to these a network of delicate nerve-fibres is distributed. These muscular and nerve fibres are, however, much more highly developed upon the newt's lung than upon that of the frog. The distribution of nerves to the muscular fibre cells of the arteries is described in Lecture XII, p. 296.

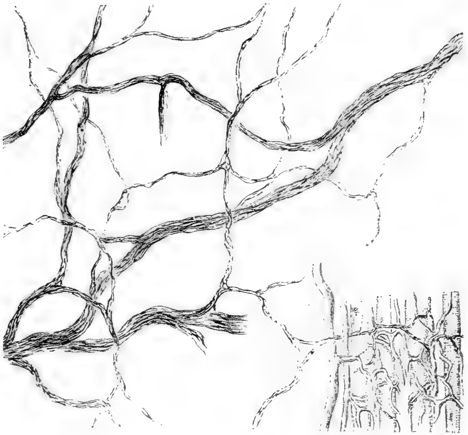
Distribution of Nerves to Striped Muscle.

273. Of the dark-bordered fibres distributed to voluntary muscle.—The plexiform arrangement of

nerve-trunks and nerve-fibres is one which is very general, and was known even to the older anatomists. Pl. IX, fig. 2, p. 245. It can be demonstrated in many cases even by rough dissection. Plexuses exist not only in the case of nerves distributed to muscle, but, as far as is known, to every other tissue which receives a supply of nerves. Many of these networks are very beautiful; and the arrangement is illustrated in many of my figures, particularly in those representing the bundles of dark-bordered nerve-fibres distributed respectively to the diaphragm of the white mouse, Plate VII, fig. 1, the mylohyoid of the green tree-frog, Plate VIII, fig. 1, and the eyelid of the same animal. The fibres constituting the bundles never run perfectly parallel, nor can a separate fibre usually be followed for any great distance. This arises from the fact that the fibres frequently cross one another, and are seen to pursue a spiral course in many instances. At an early period of development one fibre may be seen coiled spirally round the other, as is well shown in one of my drawings, fig. 2, Plate VIII. *See* also my paper "On the Structure of the so-called Apolar, Unipolar, and Bipolar Nerve-cells," Phil. Trans., 1863. The rule seems to be universal that fibres on one side of a nerve-trunk cross over and pursue their course on the opposite side. Those on the lower part of a trunk soon pass to the upper part, and *vice versâ*. Instead of a nerve passing to its distribution by the shortest route, it invariably seems to pursue a very circuitous course. Nor is the crossing of the nerve-fibres in the optic commissure peculiar to this part of the nervous system, but a similar arrangement is to be met with in all nerves. At the point where two trunks seem to meet and cross one another, it is easy to demonstrate, 1. Fibres pursuing a direct course. 2. Fibres crossing from one side to the other. 3. Central commissural fibres. 4. Peripheral commissural fibres.

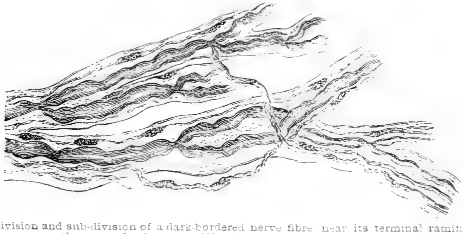
PLATE VII.—DISTRIBUTION OF NERVES TO STRIPED MUSCLE.

Fig. 1.



Division and sub-division of nerve trunks, and formation of primary, secondary, and tertiary networks of dark-bordered nerve fibres and networks of finer fibres upon the diaphragm of the white mouse. At the right-hand corner of the drawing, four of the muscular fibres with their capillaries, and some of the nerve fibres are represented × 100. p. 246.

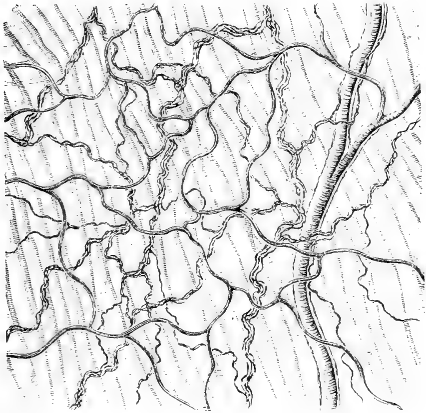
Fig. 2.



Division and sub-division of a dark-bordered nerve fibre near its terminal ramifications upon the muscular fibres. × 550 and reduced to 275. From the leg of the frog. pp. 247, 248.

PLATE VIII.—DISTRIBUTION OF NERVES TO STRIPED MUSCLE.

Fig. [illegible]



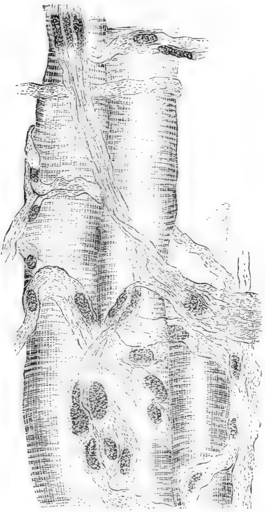
[illegible] × [illegible]

[illegible]

Dark bordered fibre with fine fibre passing spirally round it. [illegible] The nuclei of the dark-bordered fibres are nearly equidistant, and much closer together than the nuclei of the spiral fibre. The dark-bordered [illegible] consist of spindle-shaped cells or elementary parts continuous with [illegible]. From the bladder of the hyla. × 1,800 and reduced [illegible]

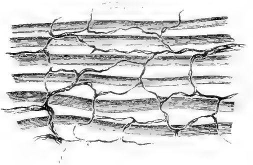
PLATE IX.—ULTIMATE DISTRIBUTION OF NERVE FIBRES TO STRIPED MUSCLE.

Fig. 1.



Muscular fibres with [illegible] nerve fibres ramifying upon them. [illegible] of the white mouse. × [illegible] In some places the appearance [illegible] 'nerve-hill' [illegible]

Fig. 2.



Network composed of compound nerve trunks ramifying over muscular fibres. Muscle Chameleon. About 1[illegible]0 diameters.

Fig. 3.

Muscular fibres seen in section showing the manner in which, according to Kuhne, the dark bordered nerve fibre perforates the sarcolemma and comes into close relation with the contractile tissue. After Kuhne. pp. [illegible]

Fig. 4.

Division of dark-bordered fibres and formation of networks of pale compound and very fine fibres. From the pectoral of the frog. × 700. p. 257.

The dark-bordered fibres distributed to the muscles of the frog often divide into two finer fibres, as represented in several of my figures, Plate VII, fig. 2, and these at last divide into two very fine fibres, which may be followed for a long distance. *See* Pl. IX, fig. 4, and Pl. XI, p. 253. The fine fibres appear pale and granular, and connected with them at varying intervals are bioplasts (nuclei). These pale nucleated fibres in the frog are often less than the $\frac{1}{50000}$ of an inch in diameter. They are nevertheless compound, consisting of bundles of still finer fibres. These in fact, although much narrower, correspond to the pale, granular, but nucleated intermuscular nerves first described by me in the muscles of the mouse, Plate IX, fig. 1, copied from the Phil. Trans., 1860. The very fine compound fibres still continue to divide and subdivide, and assist to form plexuses and networks in precisely the same manner as the dark-bordered fibres, of which they are the continuation. It is quite certain that these pale fibres are true nerve-fibres, for they are directly continuous with the dark-bordered fibres. Instead of breaking up into one or more bundles of fine fibres, a dark-bordered fibre not unfrequently divides into a finer dark-bordered fibre, and a bundle of fine fibres, as represented in one of my drawings from the frog's mesentery.

274. Of the tubular membrane or nerve-sheath.— As already stated, we find in the same nerve-trunk fine and coarse dark-bordered fibres, and we often observe exceedingly fine pale fibres running with dark-bordered fibres, § 235, the essential difference between these two sets of fibres in the same trunk being that the former set is nearer to its ultimate distribution than the latter; but in some instances it is probable that the fine fibre is a branch of the sympathetic. The fine fibre runs in the same transparent matrix (sheath) with the dark-bordered fibre. The idea of tubular membrane or sheath being an

essential and separate anatomical constituent of every individual dark-bordered fibre must be given up. For, as I showed in 1860, several dark-bordered fibres and fine fibres might run together in the same matrix, Pl. VII, fig. 2. The opinion that the fine fibres which I hold to be nerve-fibres running in the same sheath with the dark-bordered fibres, are not nerve-fibres at all, but modified connective tissue, is, however, still entertained by many observers, but the nature of these fibres is proved by the fact of their continuity with true dark-bordered fibres. The fine fibre may in many instances be followed in one direction to its ultimate distribution, and in the other to a large dark-bordered fibre.*

275. Some pale fibres are from the sympathetic.—Many of the pale fibres accompanying the dark-bor-

* The different and incompatible views existing between continental observers and myself are in some measure due to this sheath question. The so-called sheath is not a "tube" or "membrane," or "tubular membrane," which contains the other constituents of the nerve-fibre; nor is it a sheath which invests them, but it is simply a transparent matrix, in which nerve-fibres, coarse and fine, are imbedded. The so-called sheath is not formed as a special structure to invest the nerve-fibres, but it results from changes occurring in the nerve-fibres themselves. This "sheath" or "tubular membrane" of the so-called dark-bordered fibre precisely corresponds to the transparent connective tissue, in which the fine nerve-fibres are imbedded. It is a form of connective tissue, and in many situations where nerves existed at an earlier period, nothing but this so-called sheath remains. All the soluble fatty matters have disappeared, and this material, which is not readily absorbed, is left behind. Vessels may waste, and ducts and glands may waste, and leave behind them the same sort of transparent connective tissue. Moreover, as I have before stated, it is altogether a fallacy to suppose that near the peripheral distribution, every single branch of nerve-fibre is surrounded by its own separate sheath. Most of the drawings of the so-called axis-cylinder near the terminal distribution of the nerves seem to me to be diagrammatic, founded rather upon a theoretical idea of the constitution of the nerve-fibre than upon the results of actual observation.

dered fibres are doubtless sympathetic fibres, for it has been shown that there are fine fibres springing from ganglion-cells which retain the same character from their origin to their distribution, § 234. Not only has the nerve nature of the fine fibres above described been proved by tracing them from their connexion with ganglion-cells, but a dark-bordered fibre has often been observed to be drawn out so as to form a line as fine as these fine fibres. Indeed the observer often fails to trace an individual dark-bordered fibre for any great distance in consequence of its becoming exceedingly fine at the point where it crosses, or is crossed by other dark-bordered fibres. Not only so, but where a bundle of comparatively wide dark-bordered fibres passes through a small aperture, as for example in a bone, the fibres appear, as it were, drawn out to exceedingly thin threads.

276. Of the distribution of the ultimate pale "nucleated" nerve-fibres to the elementary muscular fibres.—Few anatomical questions have received of late years a larger share of attention than the ultimate arrangement of nerve-fibres in voluntary muscle. It is a matter of regret to me that although I have studied the question in many ways during the last five years, my conclusions do not accord with those of any other observer. And I must admit that although the German writers differ from one another on very important points, they, nevertheless, agree in this, that the nerves form *ends*, pass into *end-organs*, or exhibit *terminal extremities* of some kind; while, on the other hand, my observations have led me to conclude, not only that nerves *never terminate in ends in voluntary muscle, but that there are no terminal extremities or ends in any nerve organ whatever.*

There is this further broad difference between foreign observers and myself, that while they consider that each elementary muscular fibre is very sparingly supplied with nerves—a very long fibre

receiving, as is affirmed, nervous supply at one single point only—I have been led to conclude that every muscular fibre is crossed by very delicate nerve-fibres, frequently, and at short intervals, the intervals varying much in different cases, but, I believe, never being of greater extent than the intervals between the capillary vessels.

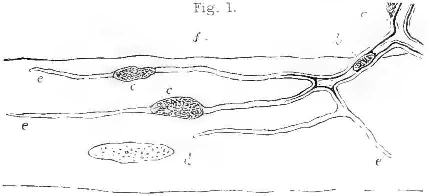
277. Kölliker's conclusions.—With regard to the ultimate arrangement of nerves in muscle, the conclusions of Kölliker accord more nearly with my own than those of any other observer. (Compare Kölliker's statements in his Croonian Lecture delivered in 1862, with the results stated in my paper, published in the Phil. Trans. for 1860.) Kölliker agrees with me in the opinion that the nerves lie upon the external surface of the sarcolemma; but what he regards as *ends* or *natural terminations*, I believe to be mere breaks or interruptions in fibres which in their natural state were prolonged continuously, Pl. X, fig. 1.

278. Kühne's views.—My friend Kühne, of Heidelberg, has probably published more papers upon this vexed question than any other observer. He maintains that the nerve always passes through the sarcolemma and comes into direct contact with the contractile tissue,* or ends in protoplasmic matter which is in continuity with the muscle, Pl. X, figs. 3 and 4. He has, however, from time to time been led to modify his view very materially, as the figures in his various memoirs, published between the years 1859 and 1864, will testify, Pl. IX, fig. 3, Pl. X, figs. 2, 4, 5. In his memoir, published in 1862, he described minutely the structure of some very peculiar organs, which he stated had been demonstrated by him in connexion with the

* This view was first advanced by Kühne in 1859 ("Untersuchungen über Bewegungen und Veränderungen der contractilen Substanzen," Reichert und Du Bois Reymond's Archiv, 1860).

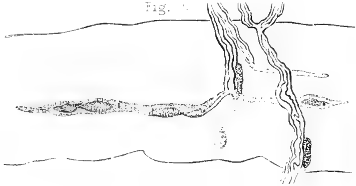
PLATE X.—SUPPOSED NERVE ENDS ACCORDING TO KÖLLIKER AND KÜHNE.

Fig. 1.



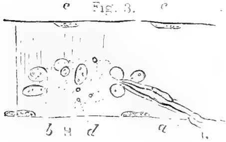
A part of one of Kölliker's figures representing the supposed *termination* of a dark-bordered tubular nerve fibre on a muscular fibre of the cutaneous muscle. Frog.

Fig. 2.



The original 'endknospe' of Kühne. pp. 260, 262.

Fig. 3.

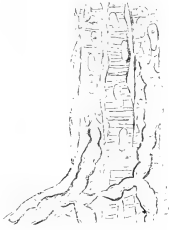


Another form of 'endknospe' of Kühne, in muscular fibre from psoas of a rabbit. × 450. pp. 260, 262.

Fig. 4.

Portion of a muscular fibre. From the eye of a dog. Showing the new form of 'endknospe' discovered by Kühne. × 450. pp. 260, 262.

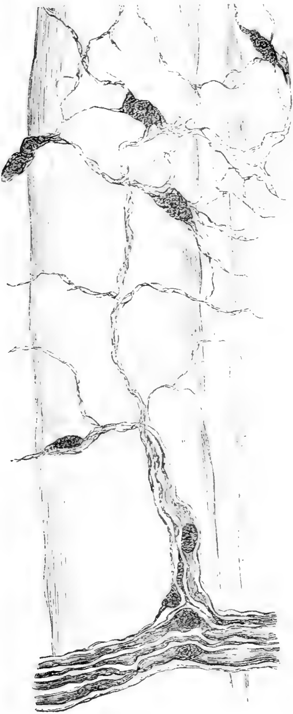
Fig. 5.



Represents the nerves in what Kolliker has termed 'nodular swellings.' After Kuhne. Here a broad dark-bordered fibre is represented as passing into a narrow muscular fibre, a conclusion obviously erroneous. Breast muscle, frog. × 450. p. 288.

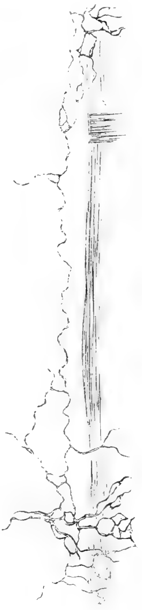
PLATE XI.—ULTIMATE RAMIFICATIONS OF FINE NERVE FIBRES ON ELEMENTARY MUSCULAR FIBRES.

Fig. 1.



Terminal portion of dark-bordered nerve fibre and fine fibres resulting from its subdivision. These form networks upon the sarcolemma. Pectoral. Frog. From a drawing × 1,300 and reduced one third. p. 257.

Fig. 2.



Portion of a muscular fibre with the finest branches of the nerves ramifying upon it. Pectoral. Frog. From a drawing × 700 and reduced to half. p. 257.

pale terminal intramuscular branches of the nerve-fibres, Pl. X, fig. 2. In more recent memoirs he seems to have abandoned the idea of the existence of those very peculiar bodies which he termed "Nerven-End-knospen," and with reason, since no other observer professes to have seen objects at all resembling those figured by Kühne. I should, however, state that the later observations of Kühne have in the main been supported by Engelmann and some other obervers.

279. Memoirs on the distribution of nerve to muscle from 1860 to 1865.

Lionel S. Beale. On the distribution of Nerves to the Elementary Fibres of Striped Muscle.—Phil. Trans., June, 1860.

Kühne. Note sur un nouvel organe du système nerveux.—Comptes rendus, Feb., 1861.

Kühne. Ueber die peripherischen Endorgane der motorischen Nerven.—Leipzig, 1862.

Theodor Margó. Ueber die Endigung der Nerven in der quergestreiften Muskelsubstanz.—Pest, 1862.

Kölliker. Untersuchungen über die letzten Endigungen der Nerven.—1862.

Lionel S. Beale. Further observations on the Distribution of Nerves to the Elementary Fibres of Striped Muscle.—Phil. Trans., June, 1862.

Rouget. Note sur la terminaison des nerfs moteurs dans les muscles chez les reptiles, les oiseaux et les mammifères. — Comptes rendus, Sept. 20th, 1862; also Brown-Séquard's Journal, 1862.

Naunyn. Ueber die angeblichen peripherischen Endorgane der motorischen Nervenfasern.—In Reichert und Du Bois Reymond's Archiv, 1862, p. 481.

Lionel S. Beale. On the Anatomy of Nerve-fibres and Cells, and on the ultimate Distribution of Nerve-fibres.—Quarterly Journ. of Mic. Science, April, 1863.

Lionel S. Beale. Further observations in favour of the view that Nerve-fibres never end in Voluntary

Muscles.—Proceedings of the Royal Society, June 5, 1863.

Krause. Ueber die Endigung der Muskelnerven. —Henle und Pfeuffer's Zeitschrift, 1863, p. 136.

Th. W. Engelmann. Ueber die Endigungen der motorischen Nerven in den quergestreiften Muskeln der Wirbelthiere.—Centralblatt f. d. Medic. Wissensch, 1863.

Lionel S. Beale. Remarks on the recent observations of Kühne and Kölliker upon the termination of the Nerves in Voluntary Muscle.—Archives of Medicine, vol. iii, p. 25.

Th. Wilhelm Engelmann. Untersuchungen über den Zusammenhang von Nerv- und Muskelfaser.—Leipzig, 1863.

Kühne. Ueber die Endigung der Nerven in den Muskeln.—Virchow's Archiv, Band 27.

Kühne. Die Muskelspindeln.—Virchow's Archiv, Band 28.

Kühne. Der Zusammenhang von Nerv- und Muskelfaser.—Virchow's Archiv, Band 29.

Lionel S. Beale. On the Structure and Formation of the Sarcolemma of Striped Muscle, and of the exact relation of the nerves, vessels, and air-tubes (in the case of insects) to the contractile tissue of Muscle. —Trans. Mic. Society, 1864.

Rouget. Sur la terminaison des nerfs moteurs chez les Crustacés et les Insectes.—Comptes rendus, Nov. 21, 1864.

Lionel S. Beale. An Anatomical Controversy. The distribution of Nerves to Voluntary Muscle. Do nerves terminate in free ends, or do they invariably form circuits and never end?—Archives of Medicine, vol. iv, 1865. Published separately: Churchill, London.

280. Distribution of nerves to the breast muscle of the frog.—As the observations of Kölliker, Kühne, and other observers in Germany, who differed from me,

were made upon the breast-muscle of the frog, while my first inquiries were instituted upon the muscles of the white mouse, I subjected this particular muscle of the frog to the same process of investigation which I had previously adopted in my researches in 1858–59, which were published in 1860. The results of these investigations will be understood by reference to the drawings, which were printed in my paper published in the Philosophical Transactions for 1862.

Although the results of this further inquiry (1862) were favourable to the view I had advanced, they were deficient in this most important point, viz., that the network which I had demonstrated over the elementary muscular fibres of the mouse, Pl. IX., fig. 1, had not been conclusively demonstrated over the frog's muscular fibres generally. Near the point where the dark-bordered fibre divided to form pale fibres, a *network* was easily demonstrated, Pl. IX, fig. 4, but it could not in many instances be traced for any great distance beyond this point. The following conclusions, however, were established in this memoir:—

1. That the nerve-fibres, as I had already stated and as had been confirmed by Kölliker, were outside the sarcolemma. Pl. XI, figs. 1 and 2.

2. That the fibres might be followed for a greater distance from the dark-bordered fibre than they had been traced before, if the specimens were prepared according to the new method of investigation which I described. Pl. XI.

3. The fine pale fibres were proved to be composed of several finer fibres, which resulted from the division of the dark-bordered fibre, as well as from the division of the pale fibre in the sheath of the nerve. Pl. VII, fig. 2. The fine fibre accompanying the dark-bordered fibres are demonstrated for the first time. Pl. IX, fig. 4.

4. Contrary to the statements of continental observers, it was proved that the elementary muscular

fibres of the frog were crossed at *numerous* points by nerve-fibres, and that the nerve supply to each elementary muscular fibre was much more free and uniform than had been supposed. This fact was demonstrated more especially in the thin muscles of the eye and in the mylohyoid of the frog.

281. Distribution of nerve fibres to the muscles of the Hyla, or green-tree frog.—Not satisfied with the results of my investigations, published in 1862, I examined numerous other muscles of the frog and other animals, in the hope of being able to demonstrate the finest nerve fibres in every part of their course over the sarcolemma, but was not able to obtain any muscle in the common frog so thin that I could trace the finest branches over a very considerable extent of surface. In the *mylohyoid* of the Hyla, however, I found a muscle eminently adapted for this investigation; and on June 5th, 1863, I presented a paper to the Royal Society upon the arrangement of the nerves in this beautiful muscle. This memoir is published in the "Proceedings." I have prepared many specimens in which the nerve can be followed from one undoubted nerve-trunk to another, dividing and subdividing in its course, so as to form with other nerves a lax network of compound nucleated fibres, which compound fibres are often less than the $\frac{1}{60000}$ of an inch in diameter. In Pl. VIII, fig. 1, I have given a sketch of this beautiful thin muscle, as it appears when examined under a low magnifying power. The vessels are injected. The nerve network is well seen, as it ramifies over the two layers of muscular fibres. The elementary muscular fibres cross one another at right angles.

282. The distribution of nerves to the muscles of Articulata.—The highly elaborate and rapid movements of insects would lead to the inference that in them the distribution of nerves to the muscles must be very free. The textures are, however, so very

delicate, and their structural elements so minute, that the difficulty of demonstration is very great. Kühne's memoir, published in the year 1860, related to the distribution of nerves to the muscles of *Hydrophilus piceus* (Dytiscus). He represented the nerve as perforating the sarcolemma, and as distributed almost in a *brush-like manner* to the contractile tissue. Subsequently he thought the nerve was connected with the line of muscular nuclei; but it was obvious that these were muscle nuclei, and not connected with nerves at all. The view was therefore abandoned, but some other observers have fallen into the same error. Although I have examined the muscles of many insects, and especially those of the *Hydrophilus*, I have been quite unable to confirm the conclusions concerning the brush-like distribution of the nerves.

283. Distribution of nerves to the muscles of the maggot.—For illustrating the distribution of nerves to the muscles of insects, I will select the common maggot, the larva of the blowfly. This insect can be obtained in all countries at almost all seasons of the year.

By reference to my drawings, it will be noticed that my conclusions accord in the most important particulars with those arrived at in my earlier investigations. The drawing out of the sarcolemma into a sort of eminence at the point where the nerve commences to ramify over it, is well seen. This has been mistaken for a special organ by Kühne (Nervenhügel); and it has been inferred that the nerve perforated the sarcolemma at this point.

In his paper in the 'Comptes rendus' for November 21, 1864, M. Rouget in part confirms my statements regarding the structure of Kühne's "Doyère'schen Nervenhügel," and states that, at the Nervenhügel, the nerve fibre divides into two fine fibres, which may be traced for some distance, but then terminate. "Leur extrémité terminale est

légèrement effilée; elle ne présente ni plaques, ni noyaux, ni substance finement granuleuse."

The structure of these so-called Nervenhügel in insect-muscles was described and figured by me in a paper, accompanied by several drawings, read to the Microscopical Society on June 1, 1864, and published in the "Transactions" on October 1. Although M. Rouget agrees with me as respects the nature of the Nervenhügel, we are at variance upon the further course and mode of termination of the nerve-fibre, M. Rouget maintaining that it penetrates beneath the sarcolemma and terminates there in a very fine fibre, in contact with a very limited portion of the contractile tissue, while I have been able to trace the nerve for a long distance beyond the point at which he makes it end, and have seen it dividing into very fine fibres, which form an extended network upon the sarcolemma, as represented in Pl. XII, fig. 1, p. 263, to which I beg to direct special attention. These nerves are excessively fine, like the ultimate branches of the tracheæ which I have demonstrated in the same specimen. The preparation from which the drawing was made was magnified nearly three thousand diameters. M. Rouget's researches lead him to conclude that the arrangement of the nerves in the muscles of Articulata is totally distinct from that met with in Vertebrata. "Il résult de ces faits qu'il n'y a pas d'identité entre les divers modes de terminaison des fibres nerveuses motrices chez les vertébrés et les articulés." On the other hand, my observations lead me to the conclusion that the arrangement is in its essential points the same in all classes of animals. In no case are there nerve-ends, but always plexuses or networks, which are never in structural continuity with the contractile tissue of the muscle.

284. Nerves to the muscles of the leech.—I have particularly studied the arrangement and distribution of the nerves in the leech. The same facts noticed

in p. 182 concerning the *branching* of nerve-fibres, are observed in the nerves of this animal; and I have been able to obtain many specimens of nerves which could hardly be distinguished from some of the finest dark-bordered fibres of the higher animals. Some of the muscular fibres of this animal are very thin, and are separated from one another by considerable intervals, in which the ramification of exceedingly delicate nerve-fibres can be readily detected, and the nerve-fibres can be followed to their connection with ganglion-cells. I have prepared many specimens of the muscles of the leech, and have made several drawings to illustrate these points.

285. Of the nerve-tufts, nerve-eminences, and Nervenhügel, seen in connection with certain muscular nerves.—To Kühne is undoubtedly due the merit of having observed the so-called *end plates* or end organs in voluntary muscle, and it is not surprising that he should have been led to regard them as the special nerve organs of this tissue, and inferred that they were present in all muscles. He has studied principally large muscular fibres, and considers these most favourable for observation, but it seems not to have occurred to him that in consequence of the refractive power of the contractile tissue, the very fine nerve fibres, if present, would be completely obscured. I do not think he has yet formed the slightest idea of the general arrangement and great number of the fine nerve fibres in voluntary muscle as may be demonstrated, for example, in the delicate mylohyoid muscle of the hyla. At least, in the chameleon, several fibres are to be seen passing *to* and *from* each nerve tuft, but Kühne has only figured a single dark-bordered fibre entering each tuft. I propose now to consider the structure of these peculiar so-called end-bodies in connection with the nerves distributed to the muscles of certain animals, and described by Kühne, Rouget, Krause, and others. These differ from the

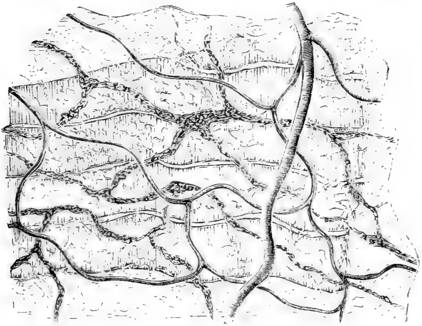
bodies first studied by Kölliker in the breast-muscle of the frog, which are referred to in p. 269. I have never been able to demonstrate such bodies as I am about to describe in the muscles of animals generally, although they are exceedingly distinct in the muscles of lizards, as shown by Rouget. I have demonstrated many in the cutaneous muscles of the neck, and in the muscles of the tongue of the chameleon, and shall carefully consider the structure of these.

In the first place, I would remark that these bodies are *external to* the sarcolemma, though adhering intimately to it, as may be proved by examination of the the specimens. The course of the nerves *to* and *from* these bodies, Pl. XII, fig. 2; Pl. XIII, figs. 1, 2, 3, renders it almost impossible that they could be beneath the sarcolemma, while in many cases the outline of the sarcolemma can be followed underneath them. Secondly, it appears probable that they are a reduplication and expansion of continuous fibres, rather than terminal organs formed upon the extremities of the nerve-fibres; nor would it seem that these organs are essential to the action of nerves upon muscle, since they are only to be demonstrated in the muscles of certain animals. Moreover, as many different forms of these nerve organs are to be seen in a small piece of muscle, exhibiting different degrees of complexity, we may perhaps by studying them attentively be able to draw a true inference as to their real structure, and the mode of their formation. Pl. XII, fig. 2.

Kühne's idea of the structure of these bodies is represented in the figures copied from his memoirs (Pl. IX, fig. 3; Pl. X, figs. 2, 3, 4). The interpretation of the appearances here given is totally different from that which I have been led to offer. In my specimens the nerve-fibres entering into the formation of these tufts are seen to divide and subdivide into several branches which are folded, as it were, upon one another, Pl. XIII, figs. 1 and 2. The nuclei seem to

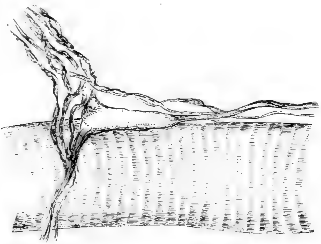
PLATE XII.—ULTIMATE DISTRIBUTION OF NERVES—'END ORGANS' OF MUSCLE.

Fig. 1.



Piece of sarcolemma with contractile matter of [illegible] from maggot of blow fly. × 3,500. The networks [illegible] of the tracheæ and nerve fibres are well seen [illegible]

Fig. 2.

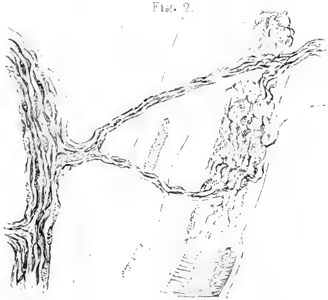


Nerve fibres distributed to elementary muscular fibre [illegible] × 3,000 and reduced half. This is the simplest form of 'nerve tuft' that can be found and is clearly external to the sarcolemma. [illegible]

Fig. 1.

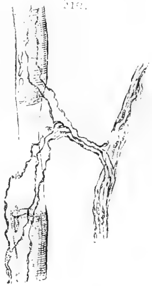
The intimate structure of a very simple nerve tuft on a muscular fibre of the chameleon. It will be observed that the nerve fibres are continuous throughout, and that the whole is on the surface of the sarcolemma (× [illegible]). This "nerve tuft" is as it were but a compound network. pp. [illegible], 267.

Fig. 2.



Nerve tuft on the sarcolemma of a muscular fibre. Chameleon. Nerve fibres are seen passing *out of* as well as into the "nerve tuft." pp. 262, 267.

Fig. [illegible]



Very simple form of nerve tuft on the surface of sarcolemma of muscular fibre, the sarcous material of which is ruptured. × 215

be connected with the finer branches of the nerve-fibres. In fact the so-called end-organ seems to consist partly of broad fibres, partly of fine fibres formed by the branching, spreading out, and coiling of the fibres resulting from the subdivision of the original nerve-fibres which enter into the formation of the tuft, Pl. XIII, figs. 1 and 2. Moreover, I have succeeded in demonstrating that, from various points of the oval coils, branches pass off and run on the surface of the sarcolemma, probably passing on to other nerve-bundles. These fine fibres, which are represented in my drawings, have not been delineated, as far as I am aware, by any previous observer, who has examined these bodies. In connection with every nerve-tuft there seem, indeed, to be 1, *entering* and 2, *emerging* fibres; note particularly the positive instance represented in fig. 2, Pl. XIII, in which the nerve-fibres can be traced to and from the "tuft" most distinctly; and in the majority of instances, fine fibres may be traced from the tuft in several different directions.

"Nerve tufts" are not terminal organs but networks.—The nerve-tuft consists of a complex network of fibres, the meshes of which are very small. Connected with the fine nerve-fibres are numerous masses of bioplasm or nuclei. The plexus or network constituting the nerve-tuft is not terminal, nor does it result from the branching of a single fibre, as has been represented. *Many fibres* enter into its formation; and from various parts of it long fine fibres pass off to be distributed upon the surface of the sarcolemma.

It seems most probable that at the situation of these compressed coils (nerve tufts) the contraction of the muscular fibre would commence, and that, from the nerve-current traversing several fibres collected over a comparatively small portion of muscle, the contraction at these spots would be sudden and

violent, while it is probable that the contractions commencing at these points would extend, as it were, from them along the fibre in opposite directions.

I consider these nerve-tufts therefore simply as collections of nerve-fibres, differing only from the ordinary arrangement before described, somewhat in the same manner as the compressed nerve-network in a highly sensitive papilla differs from the lax expanded nerve-network in the almost insensitive connective tissue.

286.—Distribution of nerve fibres to the elementary muscular fibres.—The individual muscular fibres of the tongue of the chameleon are separated from one another by a distance greater than their diameter, so that the finest nerve fibres can be seen in the intervals between them and traced over or under them without difficulty. In my specimens many of the so-called "nerve tufts" can be discerned, but in every instance more than one individual nerve fibre can be traced to the tuft, and it can be demonstrated that the "tuft" consists of continuous fibres, exhibiting various degrees of coiling. It is not a *terminal organ* connected with the end of a single *fibre*. From every one of these "nerve tufts" fibres may be traced and followed for a considerable distance over many muscular fibres beyond. Plate XII, fig. 2; Plate XIII, figs. 1, 2, 3. There are no ends nor terminations.

287.—Nerve tufts exceptional.—It seems to me most probable that these bodies are exceptional and not present in all muscles, nor essential to voluntary muscle generally. As in other tissues the peripheral arrangement of the nerves in voluntary muscle is a continuous network, in which the nearest approach to an "end" or "termination" is a loop. Kühne is, I think, wrong in concluding that the nerve tuft is situated beneath the sarcolemma and is in contact with the contractile tissue. Like many of the nerves these

bodies adhere to the sarcolemma, but are certainly not in intimate relation with the contractile material of the muscle. The course of the exceedingly fine nerve fibres of the chameleon can be followed without difficulty over perhaps thirty or more muscular fibres and their connection with the nerve bioplasts demonstrated. The general conclusions I have arrived at from investigating the structure of these bodies accord very closely with those resulting from investigations upon other tissues.

288.—Of the so-called " nerve tufts " in the breast muscle of the frog.—With reference to the nerves supplying the so-called nerve tufts in the breast muscle of the frog, I would remark—

1. That two dark-bordered nerve fibres, running in the same sheath, may often be traced to one part of the " nerve tuft."

2. Besides the dark-bordered fibre or fibres, there are invariably very fine fibres running in the same sheath.

3. That the dark-bordered fibres and the accompanying fine fibres divide and subdivide very freely amongst the young muscular fibres, and that thus quite a leash of very fine nerve fibres results, in the course of which numerous nuclei exist at certain intervals. Many of these can be followed upon or between the muscular fibres, for the distance of the twentieth of an inch or more from the oval swelling. These points were well seen in some of my specimens.

4. That the dark-bordered fibre or fibres which enter at the tuft are *not the only* nerve fibres distributed to these bundles of muscular fibres, but that invariably a bundle, consisting of two or three fine but dark-bordered fibres, is connected with the muscular fibres, at a point above or below that at which the swelling is situated, where the large fibre or fibres enter. Sometimes there are two such bundles,

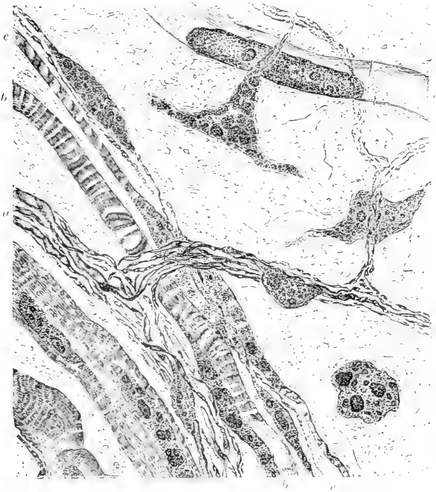
one above and one below. These not unfrequently give off branches, just before they pass to the muscular bundle, which pursue a longer course, and are distributed to other larger muscular fibres; and oftentimes branches pass from one muscular bundle to more distant ones.

From the above observations it follows that the so-called "nerve-tufts" in the breast muscle of the frog are bodies of a very complex structure. They consist of developing muscular fibres, which are freely supplied with nerves; and the number and distribution of the nerves render it probable, not only that there are *entering* and *emerging* fibres, nerve-loops, and plexuses, or networks, upon the muscular fibres, rather than *free ends*, but that the action of the new muscular fibres may be harmonized with those of the older elementary muscular fibres of the muscle by branches of nerve fibres which are probably commissural.

289. Of the arrangement of the nerve-fibres in other forms of striped muscle, as the branching fibres of the tongue, the muscular fibres of the heart, and lymphatic hearts of the frog.—To certain forms of striped muscle in which no distinct membranous tube of sarcolemma can be demonstrated, nerves are freely distributed; but all attempts to demonstrate end-organs or terminal extremities in such textures have hitherto failed. In the heart the existence of delicate nerve-fibres arranged to form networks is distinct; and perhaps the most favourable locality for demonstrating these fibres is the auricle of the frog's heart. Bundles of exceedingly fine nerve-fibres, much resembling those in the bladder, can be seen running in different directions and branching amongst the delicate networks of exceedingly fine muscular fibres. Very fine fibres may be observed in thin specimens with the aid of high powers, crossing the fine muscular fibres at different angles, then dipping down in the intervals between them, and

PLATE XIV.—DEVELOPMENT AND DISTRIBUTION OF FINE NERVE FIBRES.

Fig. 1.



Development of nerve fibres, mus[illegible] [illegible]res, and conne[illegible] tive tissue, very young [illegible]. *a*, Nerve fibre[illegible] *b*, [illegible] muscular fibre[illegible] *c*, [illegible] young [illegible] muscular fibre[illegible] [illegible] *d*, [illegible] × [illegible]

Fig. 2.

Striped muscle with fine nerve fibres, from the summit of a papilla [illegible] hyla. *a*, Fine nerve fibre. *b*, Bioplasm or nuclei of nerve fibre [illegible]

[illegible]

being soon lost in consequence of their ramification in the deeper layers.

In the drawing represented in Pl. XIV, fig. 2, the relation of the nerve-fibre to the finest part of some of the branching muscles of the tongue of the frog is represented; and I have observed an arrangement precisely similar in the case of the muscular walls of the lymphatic hearts of the same animal. The very thin and narrow muscular fibres of the heart and tongue would appear to offer very many advantages for the demonstration of ends and end-organs, supposing them to exist; but the most careful observation under the most favourable circumstances, and with the aid of the highest powers, reveals only delicate nucleated nerve-fibres, forming lax networks, branches of which may often be followed for a very long distance, and then traced into neighbouring nerve-trunks. Some fine branches of nerve-fibres which are in course of development are represented in Fig. 1, pl. XIV. Muscular fibres and connective tissue are seen in the same specimen which is magnified 700 diameters.

289.* The finest nerve-fibres which influence the muscle.—The active part of the nerve-fibre, as regards the elementary muscular fibre, commences only at the point where the dark-bordered character of the nerve-fibre ceases, and it therefore follows that the most important and most active portion of the peripheral nerve-fibres distributed to muscle, has escaped the observation of many observers. The fibres are extremely delicate, and, like other very fine nerve-fibres, can only be rendered visible by special methods of preparation. Every nerve-fibre, however fine, is compound, being composed of several fine fibres. "Nuclei" are invariably found in relation with these fibres, and they vary in number in different cases.

From the foregoing observations I conclude that the nerve-fibres which are to be regarded as the

fibres of distribution are far more delicate and much finer than has been hitherto supposed. The remarks which I make on this head with reference to the ultimate nerve-fibres distributed to voluntary muscle, will apply to the ultimate nerve-fibres distributed to other organs.

In mammalia the ultimate fibres appear as narrow, long, slightly granular, and scarcely visible bands with oval masses of bioplasm, situated at short but varying intervals, as described in my paper published in the Phil. Trans. for 1860. In many reptiles (frog, newt, lizard, snake, chameleon), however, these ultimate nerve-fibres are narrower but much firmer than in mammalia; and they are more readily demonstrated, as they do not give way under the influence of considerable pressure and stretching. Although fine nerve-fibres have been described in certain situations before I drew attention to these fine pale nucleated fibres in muscle, it was not generally supposed that the active peripheral portion of nerves exhibited these characters; nor indeed has this fact yet received the assent of many distinguished anatomists. The arrangement of the fine nerve-fibres in the summit of the papillæ of the frog's tongue, described in my last paper presented to the Royal Society (Phil. Trans. June, 1864), and in the mucous membrane of the human epiglottis, will, I venture to think, tend to convince many that the really active peripheral portion of the nervous system consists of excessively fine nucleated nerve-fibres arranged as a plexiform network [1865].

290. Diameter of the finest nerve-fibres of muscle.—With reference to the diameter of these finest branches of the nerve-fibres, many can be demonstrated and followed for long distances which are less than the $\frac{1}{100000}$th of an inch in diameter; and there is reason to think that fibres much finer than this actually exist, and serve as efficient conductors

of impressions to and from nerve centres and peripheral parts. (See Fig. 2, pl. XIV, in which very fine muscular nerve-fibres are represented magnified eighteen hundred diameters.)

291. Reply to adverse criticisms. — Professor Kühne, of Heidelberg, is one of the foremost in condemning the conclusions I have arrived at concerning the general arrangement of nerve fibres, and although he has not seen the fine fibres above referred to, he expresses himself most positively, and at least as regards the nerves of voluntary muscle, as if it were absolutely certain that he alone was right. But Kühne has himself propounded three or four different views. The first and the last differ very widely. One would have thought that the freedom exercised by him in altering his own conclusions would have induced care as regards criticising those of other observers; but he speaks as if he were an infallible authority dictating the only true faith.

It has been maintained that in voluntary muscle a dark-bordered fibre as wide or wider than the muscular fibres in the mylohyoid of the green tree frog, may pass direct to the terminal organ, while on the other hand, it is admitted that in the involuntary muscle extremely fine nerve fibres—far finer than any seen by Kühne in voluntary muscle, exist. On the other hand my preparations demonstrated that the nerve fibres in voluntary and in involuntary muscle possess the same general arrangement, and are equally delicate. If we accept the conclusions now most in favour, we must admit that the distribution of nerves to voluntary muscle is far less abundant than in the case of involuntary muscular fibre; and this, notwithstanding the fact that as an elaborate working machine, the former is beyond all comparison superior to the latter. Some anatomists would have us believe that of all tissues, voluntary muscle receives in a given area the fewest nerves,

while to a single epithelial cell some authorities maintain that many fibres are distributed;—in short we are expected to believe that a tissue every part of which we know to be eminently under the influence of the nervous system, receives very few nerves as compared with such a body as an epithelial cell of a glandular organ. As every one well knows, the structure and action of voluntary muscle actually depend upon the state of the nerves;—while it is certain that at least in very many cases the most complex secretions are formed without the existence of a nervous apparatus at all.

The fine pale nucleated nerve fibres which I was the first to describe, exist in all tissues, and constitute the active part of every peripheral nerve apparatus. Certain appearances have very recently led some anatomists to the conclusion, that these very fine nerve fibres give off still finer ones, which become continuous with the processes of the connective tissue corpuscles, the tails of epithelial cells, or pass into these bodies in considerable number, or terminate in fine free extremities; but I think this view will prove to be incorrect. When I first studied the arrangement of the fine nerve fibres, I was myself led towards a similar conclusion, but subsequent more careful observations upon well-prepared and exceedingly thin specimens of tissue, examined with the aid of the $\frac{1}{25}$ and $\frac{1}{50}$, convinced me that the nerve fibres did not enter or become continuous with the above structures;* and although there is still much doubt on several questions of detail, with regard to the arrangement of the finest nerve fibres in some special organs, new facts demonstrated from

* That I had most carefully studied and made myself familiar with the appearance of the finest ramifications of nerves is proved by the statements in my paper on the nerves of insect muscle, published in 1864. See fig. 1, Pl. XII. Having seen these excessively fine fibres, it was but natural I should search for delicate fibres in the tissues of man and the higher animals.

time to time, confirm me in the truth of the general views I have advanced on the arrangement of nerves in peripheral organs. That an observer should assert that in muscle the dark-bordered nerve fibres end almost abruptly in the nerve plates, and yet hold that in other tissues the ultimate nerve fibres are so minute that many pass into a single epithelial cell is most remarkable; but nevertheless many German anatomists, undoubtedly, having great authority, maintain that there is nothing inconsistent in accepting both statements, an opinion which could not, I think, be adopted by any one who had succeeded in following, as I have done, in several different tissues of the frog, newt, and other animals the fine ramifications of the pale nucleated nerve fibres. [1868.]

LIST OF MICROSCOPICAL SPECIMENS ILLUSTRATING LECTURE XI.

No.		No. of diameters magnified.
110.	Unstriped muscle. Bladder, frog. Showing plexuses and networks of large dark-bordered nerve-fibres..	215
111.	Unstriped muscle. Bladder, frog. Showing division of terminal portion of dark-bordered fibre into pale fibres, which form a net-work	700
112.	Unstriped muscle. Bladder, frog. Showing ultimate networks of fine pale compound nerve-fibres with their bioplasts	700
113.	Three muscular fibres from the bladder of the frog. Showing the ultimate distribution of the finest nerve-fibres	1800
114.	Fine pale nerve-fibres, distributed to unstriped muscular fibres of small artery; frog	215
115.	Division and distribution of bundle of dark-bordered nerve-fibres. Pectoral muscle, frog ..	215
116.	Distribution of fine dark-bordered nerve-fibres to very fine muscular fibres. Mylohyoid muscle. Hyla..	215
117.	Fine dark-bordered and pale fibres, distributed to very fine muscular fibres of mylohyoid. Hyla ..	700
118.	Distribution of dark-bordered nerve-fibres to the pectoral muscle of the frog. The continuations	

No.		No. of diameters magnified.
	of the dark-bordered nerve-fibres as fine pale fibres with nuclei in the intervals can be clearly demonstrated in this specimen. Kölliker thinks these soon cease and thus form *ends*, page 250, but in my specimens they may be followed much further than Kölliker succeeded in tracing them, and observations upon other muscles of the same animal render it certain that these very fine nucleated fibres come into close contact with the sarcolemma and ramify over every part of the surface of the elementary fibre	220
119.	Ultimate division of dark-bordered fibre into pale fibres, which ramify on sarcolemma. Elementary muscular fibre; pectoral, frog	215
120.	Fine pale nerve-fibres distributed to striped muscle; auricle of frog's heart. The ganglion cells are also seen	215
121.	Striped muscle. Distribution of fine nerve-fibres in connective tissue of striped muscle; hyla ..	215
122.	Distribution of bundles of nerves and vessels; thin muscle. Chameleon	215
123.	Distribution of finest nerve-fibres to elementary muscular fibres. Chameleon. Showing supposed 'end organs'	215
124.	Distribution of nerve fibres to the elementary muscular fibres. Chameleon. The individual muscular fibres are separated from one another by more than their diameter so that the finest nerve-fibres can be seen in the intervals between them and traced over or under them without difficulty. In this specimen many of the so-called 'nerve-tufts,' or 'end-organs,' can be discerned, but in almost every instance more than one individual nerve-fibre can be traced to the tuft. It seems more probable that the tuft consists of continuous fibres, much coiled and convoluted, than that it is a *terminal organ* connected with the end of a single nerve-fibre. From every one of these 'nerve-tufts' fibres may be traced and followed for a considerable distance *over many muscular fibres beyond.* The arrangement will be understood if the figs. in plates XII and XIII, pages 263, 265, be carefully studied. There are no ends or terminations whatever	700

No.		No. of diameters magnified.
125.	Distribution of nerve-fibres, with highly convoluted ramifications and bioplasts, constituting the 'end-organs.' Muscle of white mouse	215
126.	Nerve-fibres with 'end-organs.' Muscular fibres of rat	700
127.	Ultimate distribution of fine pale nerve-fibres to voluntary muscle. Frog. In the centre of the field is seen a branching muscular fibre, the fibres resulting from the subdivision of the muscular trunk, gradually taper into thin threads, which are inserted into the connective tissue. Networks of pale nerve-fibres are seen in all parts of the preparation, but the muscular tissue has been removed	220
128.	Ultimate distribution of finest nerves as networks and plexuses in the mylohyoid muscle of the hyla or green tree frog. These fibres are very narrow, and at the same time each is separated by a distinct interval from its neighbours. See pl. VIII, fig. 1. The state of things is, therefore, very favourable for the observation of the 'end-organs' if they are present. I have never been able to discover one in this beautiful example of voluntary muscle, though I have found them in many other specimens of muscle. Nerve-fibres may be traced for an immense distance from the bundles of dark-bordered fibres. Gradually they become less than the $\frac{1}{100000}$ of an inch in diameter, but still divide and subdivide into fine threads with oval bioplasts or nuclei at intervals, which, now running parallel with the muscular fibre, then crossing it, divide into branches, some of which after pursuing a very long course may at last be traced to a dark-bordered fibre in another part of the muscle. I have succeeded in doing this in many different specimens. The failure of others to obtain specimens exhibiting the same appearances no doubt depends upon a very different method of investigation having been pursued. Anatomists for the most part have not only failed to observe what I have seen, but many have not yet succeeded in demonstrating the fine pale nucleated fibres I demonstrated long ago in almost every tissue of the frog..	700

LECTURE XII.

Of the Blood-vessels and their action—Circulation of the Blood—Importance of a knowledge of the Structure of Vessels—Views regarding the Structure of the Capillaries—Protoplasm Walls of Capillary Vessels—Bioplasm of the Capillaries—Action of the Tissue of the Capillary Walls—Action of the Bioplasm—Of the Arteries—Of the Veins—Examination of the Arteries and Veins—Action of the Contractile Fibres of Vessels—Distribution of Nerves to Arteries—Nerves to Veins—Of the Nerves distributed to the Capillaries—Central Origin and Connections of the Nerves to the Capillaries—New Observations on the Nerves of the Capillaries of the Bat's-wing—Method of demonstration—Action of the Nerves of the Capillary Vessels—Are they Sensitive, or Motor, Nutritive, or Secretory?—Their Connection with Ganglia—Physiological Experiments—Of the Self-acting Mechanism by which the Supply of Blood to the Tissues is Regulated—Action of Nerve Fibres in Acute Inflammation—Alteration of Nerve Fibres in Chronic Diseases—Degeneration of Vessels.

292. Circulation of the blood in the vessels.—The nutrition and maintenance, as well as the growth, of every tissue in the body of vertebrate animals are dependent entirely upon the distribution of a due supply of healthy blood in their immediate neighbourhood. The blood does not touch the tissue to be nourished, but fluid transudes through the thin walls of the vessels along which the blood is propelled. This is imbibed by the tissue, and being kept constantly moving in its interstices, preserves the

tissues in a state of integrity, and prevents changes which would very soon take place if the fluid were perfectly stagnant. From the materials held in solution the living matter embedded in the tissue selects certain constituents, and the fluid deprived of these flows on, at last passing back again into the blood. Its place in the tissue is soon taken by a fresh portion of fluid which flows from the blood. The rate at which this nutrient fluid moves, as well as the amount distributed to the tissue in a given time, is determined in part by the influence of the living matter drawing it onwards (*vis a fronte*), and in part by the rate at which the blood flows through the vessels and the degree of tension of the thin vascular walls. The amount of fluid distributed to the tissue varies from time to time, according to the force of the heart's action, according to the quantity of blood in the body which is not always the same, the state of the arterial coats, the calibre of the smaller arteries, and a number of other circumstances.

In page 24, the course which the blood takes as it is driven through the heart has been indicated. It is there stated that the blood is driven into the large arteries (aorta to the system, pulmonary artery to the lungs) by the contraction of the muscular walls of the ventricles of the heart. The force of contraction is more than is sufficient simply to drive the blood onwards at the rate at which it is flowing through the capillary vessels, and the great arteries are consequently temporarily distended, their walls, which are elastic, being stretched. As soon as the contraction of the muscular walls of the heart ceases, the elastic arterial parietes recoil upon the column of blood, forcing it in opposite directions, back again towards the ventricle which it has just left, and onwards towards the capillaries it is about to enter. As the blood which tends to be driven back into the ventricle of the heart impinges upon the lips and fills the valves

situated at the origin of the large arteries, and causes these to flap towards one another, and close the arterial aperture, the recoil force of the elastic walls of the vessel is spent entirely in urging the blood towards the capillaries. This is the explanation of the fact well-known of the continuous flow of the blood in the capillary vessels, as proved by the uninterrupted oozing which occurs when the skin in any part of the body is cut or pricked, while in the small arteries it flows by successive jets corresponding to the beats of the heart, as is shown when an artery of a living animal is cut open.

The blood having traversed the capillary vessels passes into the minute veins which at length unite to form the two great veins of the body (venæ cavæ) which open into the right—or venous—auricle of the heart. From the right auricle the venous blood passes into the right ventricle, which drives it into the pulmonary artery and the capillaries of the lung. After it has been aërated by traversing the capillaries spread out upon the pulmonary air-cells, it is collected by pulmonary veins which open into the left auricle of the heart. From the left auricle the blood passes into the left ventricle, by which it is pumped into the aörta and the arteries of the body which come off from this large primitive trunk.

Derangement of any part of the important apparatus concerned in the circulation of the blood may indirectly give rise to disease either by alteration induced in the composition or distribution of the nutrient fluid or in some other manner. But of all the morbid affections of the organs of circulation those which affect the most minute arteries, the capillaries and smaller veins are the most common, most obscure, but by no means the least serious. For although life is not often suddenly cut short by minute structural changes occurring in these vessels, death is none the less certain to take place. Structural and too often

incurable morbid alterations in important tissues and organs are thus brought about. It is, therefore, of essential importance for us to consider the structure of the vessels and the manner in which they act. This information is the first step towards a conception of the physiological changes which are occurring in man and the higher animals during each moment of life, and without it, it is not possible to form a correct notion of the simplest general pathological change.

293. Importance of a knowledge of structure of vessels.—Without a knowledge of the structure and action of the vessels it is not possible to form an accurate notion even of the process of nutrition as it is carried on in man and the higher animals. Not only is the equable distribution of nutrient fluid dependent upon a healthy state of the organs of the vascular system, but the blood cannot retain its normal composition for long if the structure of the little vessels through which it passes be modified in any great degree. Hitherto little attention has been paid to the changes in character of the walls of the capillaries in various conditions, but there are few matters of greater importance in connection with the study of disease and the determination of the precise alterations which precede the irrecoverable loss of normal structural characters.

294. Views regarding the structure of the capillaries.—A capillary has been regarded as a simple elastic tube, the walls of which are readily permeable to fluid in both directions, which act, in fact, as a sort of filter, permitting nutrient matter in solution to flow through *from* the blood; and the products of the disintegration and decay of tissues dissolved in fluid, to flow in the opposite direction *towards* and *into* the blood. This view was in harmony with the general physico-chemical doctrines taught with such zeal in all departments of physiology a few years ago, when nutrition was regarded as a process akin to crystal-

lization, and anatomical elements (cells) were supposed to be deposited from an albuminous solution (cell stuff), just as a crystal is deposited from its mother liquor. Of late, however, very different conclusions have been arrived at, and accepted even by those who still adhere to the doctrines of purely physical physiology. It has long been admitted that capillary vessels possess "nuclei," though the office performed by these bodies had not been conclusively determined. Some thought the nuclei belonged to an epithelium *lining* the capillary vessels, but every one who studied the formation of capillaries must have satisfied himself at any rate that these "nuclei" bore the same relation to the tissue of the capillary wall as the "nuclei" of other tissues bore to the particular texture in which they were embedded. In 1865, however, Hozier. Auerbach, Eberth, Aeby, and Chrzonszczewsky,* by means of nitrate of silver, showed that the capillary wall was made up of flat elongated epithelium-like particles, much dentated at the margins, and each having a nucleus. The nitrate of silver gave rise to a black line at the point of junction of the several particles, and this fact led observers to conclude that the vessel was made of epithelial cells.

Between these particles some think they have demonstrated the openings through which, according to their opinion, red and white blood corpuscles might escape from the vessels. It was well known that blood corpuscles did, under certain circumstances, pass through the vascular walls. It was argued that such bodies could escape only through actual orifices, and the discovery of the stomata through which it was concluded they did pass, soon followed.

293. Protoplasm walls of capillaries.—But lately, the matter has entered yet another phase. We are

* See Eberth's Article, "Blood-vessels," Stricker's Anatomy, New Sydenham Society.

told by Stricker himself, that "the finer capillaries consist only of a tube composed of cells or of a cylindrical layer of protoplasm." From such a statement I must dissent, for I have studied, very carefully, the "finer capillaries" in several tissues and organs, and have never seen one in any animal to which such a description could be fairly given. At a very early period of development, of course, capillaries, like all other structures of the body, consist of what has been called "protoplasm," but when formed, the wall of the capillaries consists of a material to which the term "protoplasm" cannot be correctly applied. At one time the exigencies of favourite doctrines rendered imperative the discovery of openings in the capillary walls, and the stomata of the fancy were soon developed into "facts."

Later, however, other philosophical requirements had to be provided for. The walls of the capillaries being protoplasmic, must also be *contractile*, and Eberth declares that "the capillary wall *is* contractile," and announces that Stricker saw the capillaries "*contract* to such an extent (!) that not even a single file of blood corpuscles could traverse them," as if he were reporting some new and highly important discovery recently made by that investigator. The fact had been observed by hosts of observers long before Stricker saw the change, though it was explained in a different manner. It seemed hardly necessary to attribute it to the active property of *contractility* of the capillaries, supposed to reside in the *protoplasmic* matter, supposed to constitute the wall of the vessels. But Stricker has seen small "looplike projections raise themselves (!) from the wall of the capillaries and again become retracted;" and Eberth remarks that "it is by such contractions the corpuscles are *pressed into* the capillary wall, and ultimately made to traverse them" (!) So the corpuscles don't make their way through holes in the walls, but are as it

were, seized hold of by the contractile protoplasm and pressed through by its contractions.

The evidence adduced in favour of these doctrines is most defective—indeed, as regards their application to the phenomena of the capillary vessels of the adult, there is actually no evidence at all. No one has seen the membranous part of the wall of an adult or old capillary vessel contract, while it would be difficult to pick out a tissue less like protoplasm than the transparent material composing the capillary wall. The wall of a fully formed capillary is composed neither of *protoplasm* nor *bioplasm*, but it consists of a passive membrane permeable to certain aqueous solutions. If the thin elastic membrane of the capillary is to be called protoplasm, why should not the posterior elastic lamina of the cornea, or the thin transparent elastic membrane lining an artery be also regarded as of this nature? But these things, and living growing moving protoplasm (bioplasm) are quite different in their properties. It is indeed difficult to conceive how any one who had really studied the matter, could speak of the oval "nuclei" or bioplasts of the capillary wall and the tissue of the wall itself which intervenes between them, and was formed by them, as being composed of the same substance "protoplasm;" unless he admitted that this wonderful material might, for example, constitute the moving, changing, semi-fluid sarcode of the amœba, as well as the firm, passive, unchanging material of which, for instance, the yellow elastic tissue consists. In that case we should be applying the same name to things distinct from one another in their nature and properties. See page 9.

We shall mislead ourselves and others if we endeavour to establish resemblances which do not exist in nature, and if we ignore differences which are observable by every one who will simply examine with care and without preconceived theory. If the

oval nuclei are protoplasm, and the membranous wall is protoplasm, the student will, of course, ask us how we account for the important differences between these two things, and then we shall be driven to resort to the unfortunate expedient of suggesting that one is protoplasm, and the other is "changed" protoplasm.

296. Nuclei, or masses of bioplasm of capillaries.—More or less connected with the wall of the capillary vessel are numerous bioplasts consisting of *living matter* or *bioplasm*, which vary greatly in number in the capillaries of different tissues. Of these there are at least four distinct sets which may be distinguished in well-prepared specimens.

1. Those in the capillary wall itself, which have taken part in its formation, and which are intimately concerned in nutrition as long as blood circulates through the vessel. These vary greatly in number in different capillaries, as represented in many of my drawings, and in size also at different times. In some specimens they are extremely numerous, and, as I pointed out in 1863, project into the interior of the capillary vessel. Probably from these are detached particles of bioplasm, which pass into the blood current, and may grow into white blood corpuscles. These bioplasts are represented in Fig. 2, pl. XV, and in figs. 1, 2, 3, pl. XVI.

2. Masses of bioplasm outside, but at a varying distance from the capillary wall with which they are connected by extensions or processes. These have no doubt originated from the first by fission, and are indeed an early stage in the formation of new capillaries, as may be proved by examination of the capillaries of adipose and some other tissues which undergo great and rapid changes even in the adult.

3. Oval masses of bioplasm, generally, but not invariably, smaller than the above, and, unlike them, sometimes crossing the vessel obliquely. These are connected with the delicate nerve fibres distributed

to the capillary vessels. In some cases these bioplasts, as well as the fine nerve-fibres connected with them, are almost embedded in the wall of the capillary, but oftentimes they are seen to be separated from it by a distinct interval, which varies much in extent, as is well demonstrated in some of my specimens. The bioplasts of the nerve-fibres distributed to the capillaries are represented in Figs. 1, 2, 3, pl. XVI, and in the figures in plates XVIII and XIX.

4. Elongated and stellate masses of bioplasm which belong to the connective tissue. These vary greatly in number, size, and appearance in different tissues.

297. Of the action of the tissue of capillary vessels during life.—During life a watery solution of nutrient constituents slowly transudes through, or permeates the passive membranous tissue of the capillaries, which thus acts as a filter. If, however, the capillaries be much distended, the membranous wall is stretched and rendered thinner in a corresponding degree, and, in consequence, besides mere watery fluid, serum holding in suspension minute particles of bioplasm, traverses the capillary wall. These minute particles of bioblasm having reached the outside of the capillary remain stationary, and absorb the nutrient matter around them and grow, giving rise to important changes which cannot however be considered in this place.* In a further stage of the same process actual rents or longitudinal fissures are produced, and through these white and red blood corpuscles may pass. Loss of blood, such as may endanger life, may occur in this way, a vast quantity of blood escaping through the pores produced by undue stretching of the minute capillary vessels over an extensive surface, as for example, sometimes takes place from the small intestine. If the tension is relieved the elastic wall of the capillary contracts,

* See "Disease Germs; and on the Treatment of the Feverish State." 2nd edition.

the fissures close up, and the circulation is restored, and may be again carried on as if no escape of blood had occurred.

298. Of the action of the bioplasm of capillary vessels during life.—I have already drawn the reader's attention to the fact that in nutrition, bioplasm, or living matter, is the material which is invariably concerned in taking up and appropriating the lifeless nutrient pabulum. § 39. The latter, a product of death, is in fact altered in composition and prepared for subsequent appropriation by bioplasm. Indeed "food" consists of materials, having a peculiar composition which have been formed by special kinds of living matter. But even those constituents which so closely agree in chemical properties and composition with the substances of which the tissues of our bodies are made, that the chemist believes them to be identical, cannot be applied directly in construction. A solution of muscular tissue, for example, cannot be at once conveyed to the muscles and then converted into the muscle of our bodies. The elements of every particle must be re-arranged before it can be appropriated and taken up by the living matter of the muscular tissue. Nay, there is reason to think that substances closely resembling, or even identical with the tissues that are to be found, are as much changed as those materials of our food which are very far removed chemically from the tissues. In all cases the analytical and synthetical changes occurring in the body are effected by the bioplasm or living matter, and in these operations the bioplasm of the capillaries performs a very prominent part, § 296.

The bioplasts are exceedingly numerous, but vary in number in different capillaries. Immense numbers are found in connection with the small veins, the parietes of which indeed exhibit a structure very similar to that of the capillary. See Plate XV, fig. 2. I do not think that the appearance, copied in my

drawing, has been previously represented, though it is quite constant and to be demonstrated without difficulty if the mode of preparation I have advocated be resorted to, § 68.

I believe that the bioplasts of the capillary vessels play a far more important part in the changes of the body than has been hitherto supposed. They are as intimately concerned in the process of secretion and excretion as they are in the selection, preparation, and distribution of nutrient constituents. The bioplasts of the capillaries of the lungs are the agents by which certain animal matters are separated from the blood and transferred to the air in the pulmonary air-cells, and it is probable they are also concerned in facilitating the changes which take place between the gaseous constituents of the air and blood. In connection with the capillaries of all secreting organs the bioplasts are numerous, and they select and remove certain substances from the blood, and transfer them in an altered form to the secreting cells of the gland. They are in great number upon the vessels of the villi of the small intestines, in some cases being so very close together as to leave little membranous structure between them. These bioplasts of the intestinal capillaries receive the nutrient substances after they have been already once modified by the bioplasm of the epithelial cells of the villi, and transmit it in an altered form to the interior of the capillary, where many of its constituents are at once taken up by the bioplasts (white blood corpuscles and minute particles of bioplasm)* in the blood itself.

In many diseases these bioplasts of the capillary walls are much altered, and in cholera I have found that numbers of them have been completely destroyed. The deterioration of the vessels succeeds, and dis-

* "On the Germinal or Living Matter of the Blood." Trans. of the Microscopical Society, 1863.

organization of the capillaries of the villi, which is constantly observed in this disease, follows.* In every part of the body the bioplasts of the capillary vessels, as well as white blood corpuscles, and lymph corpuscles, are agents which take up excrementitious matter and products of decay, and pass these on in an altered form into the blood where they undergo further change, being probably split up into matters which are appropriated as pabulum, and noxious substances which are very soon excreted from the body.

299. Of the arteries.—The walls of the larger arteries consist chiefly of elastic tissue but in the intervals between the fibres of this structure, or in the meshes of the elastic network, are seen in some cases many elongated and triangular elementary parts of involuntary muscular fibre. The so-called muscular fibre cells were first demonstrated by Kölliker. I have given figures of them. It is to the presence of these bodies that the *contractility* of the larger vessels is entirely due. That these vessels are capable of contraction was proved experimentally by John Hunter, but the degree of contractile power is comparatively slight, and as far as they are concerned in the physics of the circulation the large arterial ramifications may be considered simply as *elastic* tubes.

In the smaller and smallest arteries, however, the case is very different indeed. To such a degree are the walls of these tubes capable of being contracted, that the cavity of the vessel may be temporarily obliterated. The little arteries of every part of the body undergo great changes in their calibre. Probably many times during the twenty-four hours the blood current is reduced and augmented, the vessel changing to an extent equal to two or three

* "Disease Germs: their Nature and Origin; and on the Treatment of the Feverish State." 2nd edition.

times its diameter. The blood current may, indeed, for a time, be completely stopped in consequence of the sudden and violent contraction of the muscular fibres which encircle the little vessel. See fig. 1, Plate XV, page 293, fig. 4, Plate XVI, also plates XVII and XX.

It has been suggested that the encircling muscular fibres of the small arteries by their contraction are instrumental in driving onwards the blood towards the capillaries. A number of facts, however, militate against the reception of such an idea, and are conclusive in proving that the contraction of the muscular fibres exerts only an obstructive influence. The blood current may be diminished or completely checked for a time, but under no circumstances can it be urged on by the contraction of the arterial walls.

The fibres of unstriped muscle found upon arteries are of two kinds. 1. Ordinary spindle-shaped fibres, which encircle all the small arteries of all vertebrate animals, as has been described and figured by many observers. 2. Fibres have three or four processes similar to those I have described as existing in the bladder of the frog, § 262. These last by their contraction would tend to shorten the vessel as well as to reduce its calibre, and these are probably instrumental in preventing elongation of the tube which the circular fibres would tend to produce when they contracted strongly. The fibres under consideration are found in the arteries, the coats of which are composed principally of yellow elastic tissue. In the coats of the veins these fibres pulling in three directions are also numerous.

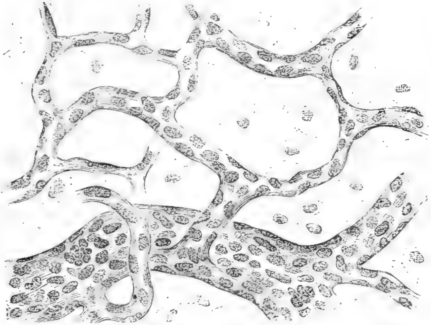
300. Of the veins.—The walls of the larger veins are composed of elastic fibres and muscular fibre cells which are more spread out and arranged with less regularity than those of the arterial coats. The smaller veins are, however, completely destitute of

PLATE XV.—SMALL ARTERY AND VEIN.

Fig. 1.

A healthy artery from the kidney of a child, 3 years old, showing muscular fibre cells and longitudinal nuclei of elastic fibres and epithelium within. × 215. p. 293

Fig. 2.



Small vein and capillary vessels, showing bioplasts which are probably concerned in the absorption of materials from the blood and from the tissues. Pia mater. Lamb. × 215. p. 295

$\frac{1}{1000}$ of an inch ——— × 215.

any muscular fibres whatever. A minute artery which is not more than the $\frac{1}{2000}$th of an inch in diameter, exhibits well defined muscular fibre cells, which encircle it closely and regularly, but upon many a vein which is as much as the $\frac{1}{50}$th of an inch in diameter, I have not been able to demonstrate one single muscular fibre cell. The walls seem to be entirely composed of very delicate connective tissue with which are connected oval masses of bioplasm in immense numbers. These are sometimes so closely placed as almost to touch one another. This important fact may be demonstrated very readily in the small veins of the pia mater if they are properly prepared with the carmine fluid Plate XV, fig. 2. The observer will be astonished at the great number of oval bioplasts in the walls of the small veins, as well as in the capillaries near the veins. These bioplasts have not, I think, been figured or accurately described, nor has attention been drawn to the very important offices they probably fulfil in connection with physiological changes that are constantly going on as long as life lasts. It must be obvious that bioplasts distributed in such number as are those in the wall of the small veins, perform other functions besides taking part in the formation of the tissue of the vein. As I have already endeavoured to show the activity of change in an organ or texture, may be judged of by the number of bioplasts present in it. In veins the bioplasts are many times as numerous as would be required to produce the very small amount of tissue entering into the formation of their coats. The blood in these small veins undergoes important changes, just as it does in the capillaries, and the agents concerned are the bioplasts. In short, physiologically, the small veins may be considered as part of the capillary system, and concerned in nutrition and in the removal of products of disintegration resulting from changes in the tissues.

301. Examination of arteries and veins.—The structure of arteries and veins may be well studied in any of the smaller vertebrate animals, especially in the frogs. In mammalia beautiful specimens may be obtained from the mouse. Those in the mesentery, the pleura, and pericardium may be subjected to examination without difficulty, but the smaller arteries and veins of the *pia mater*, or vascular membrane of the brain, and those of the folds (choroid plexuses) of the same membrane in the cavities (ventricles) of the brain are more free from connective tissue and can be easily isolated.

I have obtained beautiful specimens of the muscular fibre-cells arranged circularly round the small arteries by injecting the vessels with plain size, and gradually increasing the force so as to distend them as much as possible without rupture. In this manner the cells are as it were, gradually unravelled. When cold, thin sections may be very easily made in various directions, and even isolated fibre-cells can be obtained. The arrangement of the muscular fibre-cells in the smaller vessels, is well seen in the small arteries from the frog and newt. See fig. 4, Plate XVI and Plate XVII.

The bioplasts are to be demonstrated in specimens prepared with carmine fluid as described in § 68. I have made some very satisfactory preparations by injecting the vessels first with carmine fluid and afterwards with Prussian blue fluid, as described in "How to Work with the Microscope," 3rd edition, § 377, page 304.

The arrangement of the numerous nerve-fibres distributed to the small arteries and veins may be demonstrated in the frog with the greatest distinctness, and in connection with the small vessels which supply the viscera numerous ganglia will be found from which bundles of nerve-fibres may be traced in different directions. These often form plexuses

PLATE XVI.—DISTRIBUTION OF NERVES TO ARTERY AND TO CAPILLARY VESSELS.

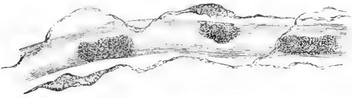
Fig. 1.

Nerve fibres distributed to capillary vessels Skin of frog. × 215. p. 308.

Fig. 2.

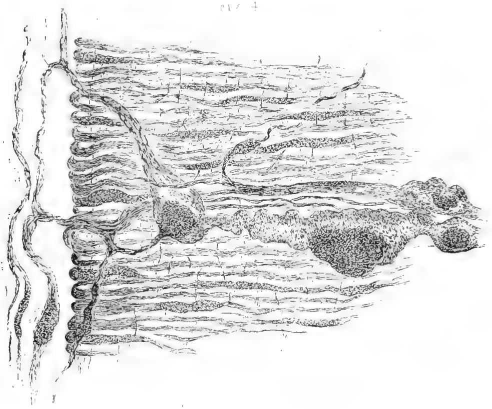
Small capillary with nerve fibre running over it Human subject. × 700 p. 308

Fig. 3.



Nerve fibres distributed to capillary vessel. Frog × 700. p. 308

Fig. 4.



A portion of the coat of the iliac artery of frog, showing muscular fibre cells, with nerve fibres. In the centre of the drawing are some large ganglion cells in process of development, from which some of the nerve fibres arise. Under *a*, a fine branch of nerve fibre passes beneath the muscular fibre × 700. pp 292, 301.

$\frac{1}{1000}$th of an inch ———————— × 700.

around the vessels and give off finer bundles, and fibres may be followed even to the capillary vessels.

302. Of the action of the contractile muscular fibre-cells.—Although the action of the muscular fibre-cells of arteries is admitted by all, there still exists in the minds of many physiologists, some doubt concerning the precise manner in which the contractility of the muscular fibre-cells is occasioned. As will presently be shown, observers are not agreed that all arteries are supplied by nerves, and many still seem to think that the muscular fibres of arteries and indeed, unstriped muscular fibres in other parts, are caused to contract altogether independently of nervous influence. *See* page 237.

The contact of the blood with the inner wall of the vessel, the stretching of the arterial walls by the action of the heart upon the contained column of blood, the movement of tissues outside of the arteries, the action of the gases dissolved in the blood, are some of the phenomena to which may be attributed the contraction of the muscular fibre-cells of the small arteries and the consequent temporary reduction of their calibre, supposing there are no nerves.

I shall endeavour to show in the course of the following pages, that the facts now known to us concerning the nerves of the smaller vessels, justify the conclusion, that the little arteries contract only through nerve-influence, and that, in all cases in which contraction of a little artery occurs during life, there is reason to think that the movement which results, succeeds to and is a consequence of a change in the nerve-fibre. As already stated in another part of this volume, there is reason to think, that to every kind of contractile tissue, nerve-fibres are distributed, and that these nerve-fibres are essentially the agents through which the change constituting contraction is brought about in the normal state. There can, however, be no doubt that the material of which

the muscle is in great part composed, possesses the property of contraction when it is removed from the muscle. Unless this was the case no influence could be produced upon muscular tissue through nervous agency.

Until very recently, it was concluded that the arteries might contract independently of nervous influence, and indeed, up to this very time, the most confused ideas prevail upon the subject.

Kölliker made the remarkable statement that some of the arteries are destitute of nerves, and that the walls of arteries are not in such need of nerves as is usually supposed. But Eberth, in Stricker's 'Handbook,' just published, says, "with the *exception of the capillaries*" the presence of nerves has been demonstrated in (upon) all vessels, but remarks that he has not been able to convince himself of the precise mode in which they terminate, especially as regards the muscular fibres of the arteries and veins. It is some years since I was led to the conclusion that all forms of muscle are supplied by nerve-fibres, and I am convinced that every small artery possesses nerve networks even in those instances in which I have myself failed to demonstrate the nerves; and it may now be regarded as certain, not only that all forms of muscle are supplied with nerves, but that these nerves form terminal networks and originate in ganglia.

Arrangement of the Nerves distributed to Vessels.

303. Distribution of nerves to the arteries of the frog.—In the external areolar coat of the larger arteries, numerous networks and plexuses of nerve-fibres may be demonstrated with facility, and in connection with the ramifications of the vessels of the thorax and abdomen, ganglia, and ganglion cells are to be demonstrated in great numbers. (Phil. Trans.) These points may be made out without difficulty in

the common frog, hyla, newt, toad, and in the snake, slowworm, tortoise, and other reptilia.

I have given a drawing in Pl. XVI of a small ganglion in course of development removed from one of the iliac arteries of the frog. Several fine branches of nerve-fibres can be followed amongst the muscular fibre-cells of the artery in the same preparation. I have seen very fine nerve-fibres beneath the circular muscular fibre-cells, apparently lying just external to the lining membrane of the artery, and composed of longitudinal fibres with elongated nuclei—an observation which confirms a statement of Luschka's. I have not succeeded in satisfying myself that nerve-fibres are ever distributed to the lining membrane of the artery, although, from the appearances I have observed, I cannot assert that this is not the case. In the auricle of the heart and at the commencement of the venæ cavæ, very fine nerve-fibres unquestionably ramify very near indeed to the internal surface, being separated from the blood only by a very thin layer of transparent tissue (connective tissue).

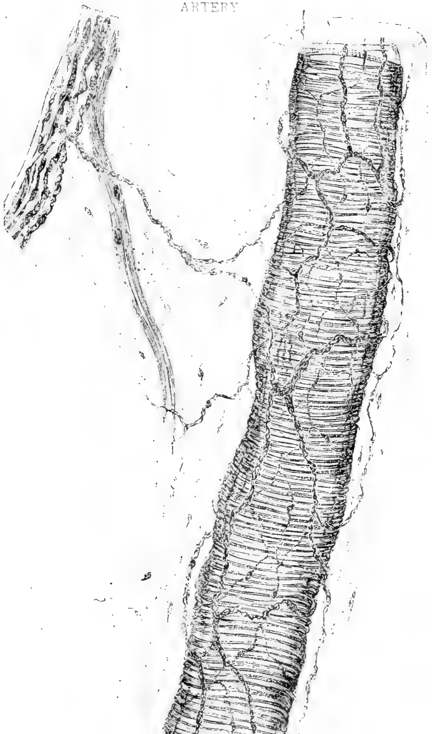
The distribution of nerve-fibres to the coats of a small artery about the $\frac{1}{800}$th part of an inch in diameter is represented in fig. 2, Pl. V, p. 216, and to somewhat larger vessels in fig. 4, Pl. XVI, and in the fig. in Pl. XVII, p. 303. In all cases (and I have examined vessels in almost all the tissues of the frog), not only are nerve-fibres distributed in considerable number upon the external surface of the artery, ramifying in the connective tissue, but I have also followed the fibres amongst the circular fibres of the arterial coat. The nerves can be as readily followed in the external coat as in connective tissue generally; and the appearance of the finest nucleated nerve-fibres, already alluded to, enables one to distinguish them most positively from the fibres of the connectiv tissue in which they ramify.

These nerves invariably form networks with wide

meshes. I have demonstrated such an arrangement over and over again. A similar disposition may be seen in the auricle of the frog's heart, in the coats of the venæ cavæ near their origin from the auricle, among the striped muscular fibres of the lymphatic hearts of the posterior extremities of the frog, and in other situations. Kölliker confesses that he has not succeeded in observing distinct *terminations* to the nerves distributed to the vessels. He states that some arteries are completely destitute of nerves, and, apparently without having given much attention to the subject, says "hence it is evident that the walls of the arteries are not in such essential need of nerves as is usually supposed." It is easy to demonstrate nerves in considerable number on all the arteries of the frog, and in the case of certain vessels of man and the higher animals in which we have failed to demonstrate nerves, it is more reasonable to assume that they are there, although they have not been seen, than to infer their absence simply because we have failed to render them distinct. In the case of the umbilical arteries of the fœtus and their subdivisions in the placenta, it is quite certain that there are no true dark-bordered nerve-fibres, but we now know that the active part of a nerve may consist of an exceedingly delicate, pale, and scarcely visible fibre, connected with a nucleus. Such delicate fibres and nuclei are to be demonstrated amongst the muscular fibres of these arteries, but in consequence of not having been able to trace them continuously for any great distance, I cannot assert that they are true nerves. No one, however, has yet proved that they are not nerves, or has demonstrated their real nature.

The nerves which supply the small arterial branches in the voluntary muscles of the frog, come from the very same fibres which give off branches to the muscles. I have seen a dark-bordered fibre divide into two branches, one of which ramified upon

PLATE XVII.—DISTRIBUTION OF NERVE FIBRES TO SMALL ARTERY



A small artery from the bladder of the hyla or green tree frog, showing the distribution of fine nerve fibres to the muscular fibre cells of the vessel. The nerve fibre can be followed from the nerve trunk to the vessel. In the connective tissue to the left are seen two muscular fibre cells with nerve fibres distributed to them. × 215. p. 301.

$\frac{1}{1000}$ of an inch ---— × 215.

an adjacent vessel, while the other was distributed to the elementary fibres of the muscle. In my paper "On the Structure of the Papillæ of the Frog's Tongue" these statements have been confirmed; and in some of my specimens, nerves distributed to arteries and to elementary muscular fibres of striped musle are seen to be derived from the same trunk of dark-bordered nerve-fibres.—Croonian Lecture, Proceedings of the Royal Society, May, 1865.

304. Distribution of nerves to arteries of mammalia.—With regard to the distribution of nerves to the organic muscle of mammalia, I have to observe that the extreme delicacy and translucency of the fibres renders demonstration most difficult. I have, however, succeeded in tracing very delicate fibres from ganglia, situated between the muscular and mucous coat of the small intestine of the white mouse to their distribution amongst the muscular fibre-cells. Still more recently, I have been able to follow nerve-fibres to the small arteries, as well as to the capillaries (page 313) of the bat's wing.

In order to successfully demonstrate the distribution of fine nerve-fibres, it is necessary to have excessively thin specimens in which the relations of the various tissues to one another have not been disturbed by the fraying out and pressure to which the section must needs have been subjected.

305. Distribution of nerves to veins.—Nerves ramify in the external areolar coat of the veins as in that of the arteries. The thin muscular coat of some of the smaller veins is abundantly supplied with fine nerves, which ramify upon and amongst the muscular fibres, and, at least in some instances, even in greater number than upon arteries. I have also detected nerve-fibres just outside the smallest veins, arranged in much the same manner as those distributed to the capillary vessels. In the bat's wing I have succeeded in demonstrating these fibres very distinctly. As the

small veins are allied to the capillaries in structure fig. 2, Pl. XV, page 293, § 300, we may conclude they act in the same manner, and that the nerve-fibres distributed to them, belong to the same system as the nerves of the capillary vessels with which they are in fact, in direct continuity.

306. Of the nerves distributed to the capillaries.—While studying the distribution of nerves to striped muscle in 1860,* I had seen nerves lying close to capillary vessels, and during the next two years obtained several preparations from the frog, toad, and newt, in which pale delicate nerve-fibres, which had been followed from trunks containing dark-bordered nerve-fibres, were discovered running by the side of almost every capillary vessel ramifying over an extensive area of tissue. In 1863, some drawings were published,† and in my Croonian lecture to the Fellows of the Royal Society, in May, 1865, the distribution of nerves to capillary vessels was briefly described, and the function performed by them discussed. Although I have incidentally referred to the fact in several lectures and papers published since this period, I have not collected my observations, nor until now have I entered into the matter so fully as it deserves. The subject appears, however, to have been almost completely passed over by other anatomical observers in this country and on the Continent. After the paper, from which I copy these observations, had been read on December 6th, 1871, at the Microscopical Society, Dr. Klein showed me some plates to illustrate a memoir by him upon the same subject, which was to appear in the January number

* "On the Distribution of Nerves to the Elementary Fibres of Striped Muscle," "Phil. Trans.," June, 1860.

† "On the Structure and Formation of the so-called Apolar, Unipolar, and Bipolar Nerve Cells of the Frog." May 7, 1863. "Phil. Trans.": Part II., 1863. Published separately. Churchill. 1864.

of the "Quarterly Journal of Microscopical Science." His specimens were prepared by the gold process, and give a different idea of the arrangement of the nerves to that afforded by mine, some of which are ten years old. I propose to restrict myself in this place to the description of the facts I have succeeded in demonstrating. Dr. Klein's memoir may be consulted by referring to the "Quarterly Journal of Microscopical Science," January, 1872, while mine, from which the following paragraphs have been extracted, was published in the "Monthly Microscopical Journal" of the same date.

My own conclusions on the ultimate distribution of nerve-fibres were formed several years ago, at a time when terminal nerve networks were denied in Germany, and when it was supposed that only in a few exceptional cases did the axis cylinder of a nerve extend beyond the white substance. Not only are my networks of pale nucleated nerve-fibres now accepted, but it is maintained that much finer networks of nerve-fibres ramifying upon and amongst epithelial cells and other elementary parts, and even upon an individual mass of bioplasm (nucleus), have been demonstrated. At present, however, I cannot regard the observations upon which it is desired to establish this view, more conclusive than those which a few years since led many to the conclusion that the axis cylinder sprang from the nucleus or nucleolus of the central nerve-cell.

I have demonstrated that nerve-fibres are distributed to capillary vessels in almost all the tissues of the frog and newt. Among these textures I would particularly mention the *skin* and *mucous membranes*, *lung* and *kidney*, the *pericardium* and *fibrous membrane near the liver*, and the *mesentery*, as well as *muscle and nerve*.

The nerves distributed to capillary vessels are much more difficult to demonstrate in mammalia, but

I am sure that they exist, and in considerable number. The tissues of man and the larger mammalia are very unfavourable for so delicate an investigation, in consequence of the very diaphanous character of their nerve-fibres and the great density of the connective tissue in which they are embedded, but in the mouse, shrew, mole, and some other small animals, they may be distinctly seen in very thin preparations. More recently I have obtained some most excellent preparations from the bat's wing. In these, nerves to the capillaries may be demonstrated conclusively with the aid of a $\frac{1}{12}$th. The $\frac{1}{25}$th brings them out still more clearly. In the preparation I showed at the Microscopical Society, which was placed under the twelfth of an inch object glass, many delicate nerve-fibres could be seen with great distinctness running very close to almost every one of the capillary vessels. In order to demonstrate this fact, it is necessary to remove the dark cuticular covering from both surfaces of the membrane of the wing—an operation by no means easy, nor always followed by success.

307. Arrangement of the nerve-fibres distributed to the capillaries.—With regard to the general arrangement of these delicate nerve-fibres, it is to be remarked that in many instances a fibre may be seen running on each side of a capillary vessel. The two fibres are often connected by short branches which pass over or under the vessel. Plate XVI, figs. 1, 2, 3, Plates XVIII, XIX, and XX.

Not unfrequently the nerve is so close to the capillary that it cannot be seen distinctly in all parts of its course, but oftentimes the capillary shrinks after death, and then a distinct interval is left between its walls and the nerve-fibre (Plate XIX, fig. 1). In some cases the nerves are still more numerous, and in the bat's wing I have seen three or four very fine fibres ramifying over a capillary for a short distance.

(Plates XIX and XX). Over the capillary vessels of the mucous membrane of the frog's palate, these fine nerve-fibres are easily demonstrated, and oftentimes may be seen a complete plexus of delicate nerve-fibres with numerous oval and triangular masses of bioplasm connected with them. Upon the capillary loop of the fungiform papillæ of the human tongue (young subject) I have seen very fine nerve-fibres in considerable number. Over the capillaries of the ciliary processes of the eye fine nerve-fibres ramify very freely. All these nerve-fibres are connected with oval masses of bioplasm, which vary in size and number in different animals and in different tissues of the same animal. In some cases the bioplasts are separated by a considerable distance from one another ($\frac{1}{50}$th of an inch), but often they are not more than $\frac{1}{500}$th of an inch apart. At the point where a fine branch divides into two others the mass of bioplasm is triangular; and specimens in which four, or even five excessively delicate nerve-fibres diverge from a mass of bioplasm with as many angles is occasionally met with. Thus, as in other situations, lax networks are formed, the meshes of which are for the most part long and narrow.

308. Central origin and peripheral connections of nerve-fibres distributed to the capillaries.—As regards the origin and connections of nerve-fibres ramifying upon the capillary vessels, I have some important facts to record.

1. In many instances, particularly in the fibrous membrane about the bladder of the frog, I have followed fine nerve-fibres from ganglion cells to the smallest arteries, where they form a plexus from which pass branches direct to the capillaries.

2. I have traced nerves direct from the ganglia embedded in connective fibrous tissue to the capillaries.

3. One of my specimens proves that a fine nerve-

fibre given off from a bundle of dark-bordered fibres distributed to voluntary muscle may be followed direct to a capillary. See Plate XIX, fig. 1, p. 315.

4. From the ganglia between the muscular and mucous coats of the small intestine of any small animal (mouse, mole) fine nerve-fibres can be followed in considerable numbers, and traced to the capillaries of the mucous membrane. I have never been able to see them on the vessels of the villi, but feel convinced they are to be demonstrated as far as this point. Even in the human subject, I have succeeded in making some good, though not perfectly demonstrative specimens.

5. "I have seen a dark-bordered nerve-fibre divide into two branches, one of which ramified upon an adjacent vessel, while the other was distributed to the elementary fibres of the muscle." Also, as already stated, "nerves distributed to arteries and to elementary fibres of striped muscle have been seen to be derived from the same trunk of dark-bordered fibres." —(Croonian Lecture, "Proceedings of the Royal Society," May 11th, 1865.)

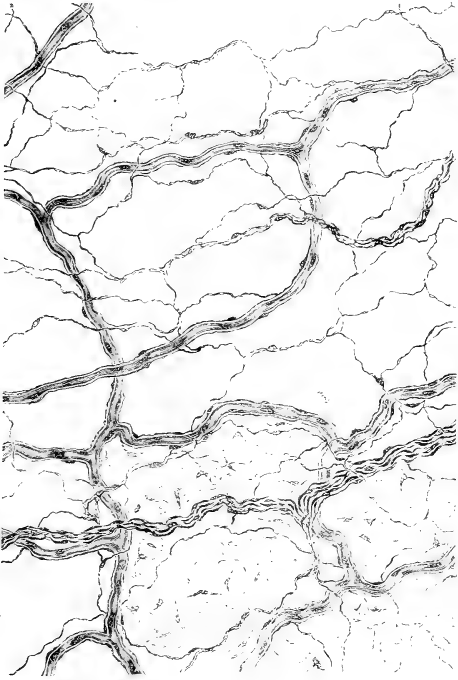
With reference to the peripheral connections of nerves distributed to capillaries, I have to remark—

1. That in the papillæ of the frog's tongue, I have followed fibres from the expansion of the sensitive nerves above the capillary loop to the capillary vessels, and also from a somewhat similar structure in the mucous membrane of the snake's mouth to the capillaries. In both cases fibres are also given off from the bundles of dark-bordered fibres before they break up to form the reticulated sensitive expansion.

2. The bundles of sensitive fibres which break up and form expanded networks in the meshes of the beautiful capillary network at the extremity of the mole's nose give off fibres which may be traced to adjacent capillaries.

3. Branches from the nerve-fibres ramifying over

PLATE XVIII.—DISTRIBUTION OF FINE NERVE FIBRES TO CAPILLARY VESSELS.



Connective tissue covering part of the mylohyoid muscle of the frog, and extending from its posterior portion, showing capillaries and nerve-fibres distributed to them. *a*, Capillary vessels, with their nerve-fibres. *b*, Bundles of fine dark bordered nerve fibres, from which fine nerve-fibres may be traced to the capillaries, as well as to their distribution in the connective tissue, where they form networks of exceedingly fine compound fibres. The engraving represents the specimen as if magnified only 110 diameters, but the original drawing was taken from it when placed under a much higher power. The specimen was mounted in 1863, and still (1872) demonstrates the points represented in the drawing. p. 308

the minute arteries may be frequently followed from these to the capillary vessels.

4. In the case of the striped muscles of the chameleon's tongue, I have succeeded in following a fine fibre from the so-called nerve tuft to the neighbouring capillary vessels.

5. In the muscular coat of the frog's bladder, in that of the oviduct, and in the muscular coat of the small intestine, the fine nerves form an intricate interlacement, some fibres of which are distributed to the muscles, while others ramify upon the little arteries, veins, and capillaries.

These nerve-fibres distributed to the finest capillaries of many tissues have therefore been traced from *ganglia*, from *sensitive and motor nerve trunks*, from the *peripheral ramifications both of sensitive and motor nerves*, and they are intimately related to the ultimate ramifications of some of the *nerves of special sense.*

These anatomical facts suggest many considerations bearing upon the mode of action of the peripheral portion of nerve-fibres, but the subject is too extensive to discuss in this place. It may form the subject of a separate memoir.

309. Recent observations on the distribution of nerves to the capillaries of the bat's wing.—More recent observations on the capillaries of the bat's wing have, however, convinced me that nerves distributed to the capillaries of mammalia, follow the same general arrangement as those traced to the capillary vessels of batrachia.

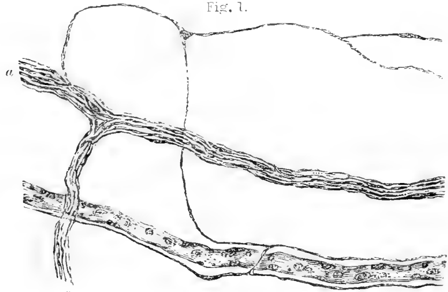
The nerves to the capillaries of the bat's wing are very sharp and defined in successful preparations, but in many specimens not a trace of them is to be discovered. The slightest alteration in the medium in which the examination is made, causes these delicate fibres to become indistinct, and unless the specimen be exceedingly thin they cannot be seen at all.

It is so very difficult to demonstrate nerve-fibres in connection with the capillary vessels of man and the higher vertebrata, that for some time I was disposed to doubt whether nerves were distributed to capillary vessels generally. I had seen such nerves in the white mouse and in the mole, also in the rabbit and Guinea pig, but as I could not demonstrate them in every instance, and in all parts of the body in which I looked for them, I could not feel sure that the presence of nerve-fibres close to capillary vessels was not owing to some special and perhaps exceptional circumstances. Investigations upon these nerve-fibres in the bat's wing were, however, conclusive. The arrangement of the delicate nerve-fibres and capillaries in this tissue is very beautiful. After long soaking in glycerine the skin may be removed from both surfaces of the thinnest part of membranous tissue of the wing, and the specimen mounted under the thinnest glass, in order that it may be examined by the $\frac{1}{25}$th of an inch object glass. I have given a figure of the capillaries and nerve-fibres as they appear under a quarter of an inch object glass in Plate XIX; and in the following plate is a drawing of a portion of a capillary vessel with its nerve-fibres, as they appear under a magnifying power of 700 diameters. The division and subdivision of the finest branches of the dark-bordered fibres is well defined, and the distribution of some of the fine pale nerve-fibres to the capillary is represented. The two drawings should be carefully examined, as a great many points of interest and importance are represented, which I cannot describe in detail here. The arrangement here delineated is very different from that figured and described by Dr. Jos. Schöbl, in his paper on the bat's wing, published in the first part of the seventh volume of Max Schultze's Archives, 1870.

The method of preparation adopted by Schöbl, does

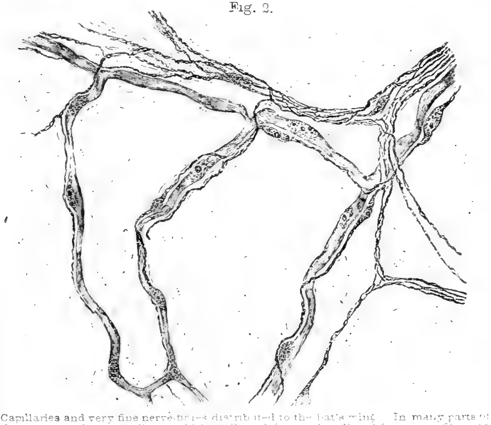
PLATE XIX.—DISTRIBUTION OF NERVES TO CAPILLARY VESSELS.

Fig. 1.



From an interval between the fibres of the mylohyoid muscle of the hyla. *a*, Trunks of fine dark-bordered nerve-fibres, with fine fibres coming from them, one of which may be traced to the capillary, while others are distributed to the muscular fibres which are not represented in the drawing. The arrangement of the nerves supplying the capillary vessel is well seen. From a specimen nearly ten years old. × 215. p. 310.

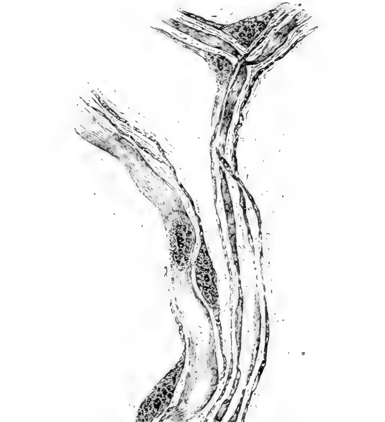
Fig. 2.



Capillaries and very fine nerve-fibres distributed to the bat's wing. In many parts of the specimen the nerve-fibre could be followed from a bundle of fine nerve-fibres to the capillaries. × 215. p. 315.

$\frac{1}{100}$ of an inch ——— × 215.

PLATE XX.—NERVES TO CAPILLARIES OF BAT'S WING



Capillary vessels with fine nerve-fibres distributed to them. A small trunk of very fine nerve fibres crosses the capillary, and gives off a branch to it. In the nerve trunk are seen some of the finest divisions of the dark bordered fibres. These are less than the $\frac{1}{20000}$ of an inch in diameter. From the bat's wing. × 700. p. 319

not render clear the arrangement, even of the nerve-fibres constituting the large trunks. Of the division and subdivision of the nerve-fibres so very distinct in every part of my specimens (see Plate XX) not an indication has been given in Schöbl's beautiful drawings. The method of preparation I have adopted seems, so to say, to carry one a long way further into the wonderful details of minute structural arrangements than the processes of preparing specimens usually resorted to.

I have already described the method pursued. It is that which I have followed for more than ten years, and which in my hands has been most successful, and is given in "How to Work with the Microscope," 4th Edition, and in the "The Physiological Anatomy and Physiology of Man." By Dr. Todd, Mr. Bowman, and myself. Second Edition. Part I, page 57. I feel sure that the plan is capable of further improvement in practical details, and that, upon the principles which I have laid down, delicate structures, which have not yet been seen by man, will be demonstrated by patient and well-practised observers. The process is troublesome, and for this reason it has not been in much favour. In these days investigation must be conducted with great haste, and new facts discovered very quickly. There is therefore little chance of getting many persons to spend sufficient time in mere practice to enable them to gain the requisite skill for the very much more minute investigation by which alone the structure of the most delicate textures which is now so much desired can be demonstrated, and which must be carried out before we can hope to arrive at positive conclusions on fundamental anatomical questions of the greatest importance. At the same time, it seems scarcely fair on the part of observers who object to one particular method of enquiry, to condemn it, and to mistrust the results without having examined the specimens.

310. The action of the nerves distributed to the capillary vessels.—We have now to consider the office of the nerve-fibres distributed to the capillary vessels which I have been fortunate enough to demonstrate in the tissues of so many vertebrate animals, as to leave no doubt that they are constantly present and discharge a highly important office in connection with general physiological changes going on in all parts of the organism. These nerve-fibres of the capillary vessels are essential. If they are deranged or damaged the healthy action of the tissue or organ involved is no longer properly discharged, while if the nerve-fibre be destroyed the nutrition of the tissues adjacent to the capillary must suffer. If the nerve-fibres distributed to the capillaries extending over a considerable area be destroyed by disease or damaged indirectly owing to changes having taken place in the nerve-centres connected with them, serious derangement of the function of the organ involved is the result, and a diseased state immediately follows, which may progress quickly or very slowly until at last much normal tissue, which cannot possibly be replaced, is completely destroyed. In many organs such changes will cut short life, either immediately or after prolonged suffering from progressive structural change.

It is very desirable, therefore, to determine the exact action of a nerve mechanism which plays so highly important a part in man and the higher animals in health and in disease. With this object I propose now to consider what is the nature of the work discharged and the way in which it is performed by the nerves distributed to the capillaries, the arrangement of which had been described.

Are the nerve-fibres of the capillaries sensitive?—Considering the arrangement of nerve-fibres in the organs of sense, no one would be likely to infer that those distributed to capillary vessels were in any way

concerned in special sensation. We know that many of the ultimate parts of organs which take part in sensation—which, indeed, constitute the active portion of the sensitive apparatus, are destitute of vessels altogether. These and other considerations render it almost certain that the nerve-fibres of the capillaries are not nerves of sense.

Are they motor?—The capillaries are not provided with muscular fibres, nor is there any contractile tissue to be demonstrated in connection with them. Although it has been confidently asserted that the capillary walls consist of *protoplasm* (!), anyone who will be at the pains of examining actual capillaries, as, for example, those of the pia mater, will soon be convinced that this view is a mistake. It is, as I have shown, one of those conjectural anatomical observations which are in favour in these days. An hypothesis was advanced to account for the passage of blood corpuscles through the capillary walls, and this and other hypotheses rendered it necessary that some one should demonstate the *protoplasmic character of the capillary walls*. Protoplasm has been therefore conjecturally discovered in the capillaries by more than one microscopical philosopher.

The *membrane* of which the walls of capillaries are in part composed can be seen, and the bioplasts connected with it demonstrated in considerable number, and without difficulty. The membrane is transparent, slightly fibrous in the vessels of old animals, highly elastic, but destitute of any structure that can be regarded as *contractile*. We may therefore, I think, dismiss the idea that these nerve-fibres are motor, or are in any way concerned directly,—that is, by any influence exerted by them on the walls of the capillaries,—in reducing the calibre of these minute vessels. If protoplasm could only be proved to exist in the walls of the capillaries, the presence and action of the nerve-fibres would be accounted for. It would

be inferred that through their intervention the protoplasmic substance was excited to contract. But if the capillary walls do not consist of protoplasm, such a theory is altogether inadmissible.

Are they nutritive or secretory in their action?—I must ask the reader to consider with me whether it is probable that these nerves are connected with nutritive or secretory operations. Now, although many high authorities still hold to the opinion that nerves do act directly upon the nutritive process, many considerations render it at least doubtful whether the action of secreting cells is directly influenced by nerve-fibres in any case. Nutrition and growth and secretion are carried on at a rapid rate in many structures which are destitute of nerves, and at every period of life. In disease the most active nutritive changes occur in tissues which appear to be wanting in nerve-fibres. For example, the formation of pus from epithelium and the formation of tubercle, can hardly be attributed to the influence exerted by nerves, seeing that the phenomena occur in parts to which nerve fibres do not reach, and yet the quantity of nutrient matter taken up in a short time is very considerable. Again, nutrition and growth are most active in all living beings at a period of development anterior to that when nerves are formed. Secretion is very active in glands which receive a limited supply of nerves, and in those parts of glands to which very few nerves are distributed. Contrast, for example, the multitudes of fine nerve-fibres ramifying upon the surface of a sensitive mucous membrane, with the few that can be traced around the uriniferous tube, or followed to the follicles of the sebaceous glands, or to those of the salivary glands. Pflüger's statements on this point have not been confirmed by other observers, and from my own observations I am convinced that if, as Pflüger asserts, nerve-fibres are distributed to secreting cells, they are arranged diffe-

rently and are in character very different from that represented in his drawings. In those cases in which nerves can be followed near to secreting cells, it is more probable that their function is *afferent* as regards the nerve-centre governing the nearest vessels, than that they are directly concerned in the actual secerning process, which I believe to be due rather to the properties and powers of the bioplasm of the cell, than to any mysterious, and at this time purely conjectural, influence of nerve force.

What is their office?—What, then, is the probable office of the nerve-fibres which are so freely distributed to many of the capillary vessels? Upon many sensitive surfaces the fine nerve-fibres running very close to the capillaries are indeed so numerous that we can hardly avoid coming to the conclusion that these very nerve-fibres must be concerned in sensation. The capillaries of the mucous membrane of the frog's palate, for example, are surrounded by a complete network of very delicate nerve-fibres, which lie immediately beneath the epithelium. In this situation there are no *papillæ*, nor is there any form of sense organ to be discovered. By experiment we know that this surface is eminently sensitive, but there is no reason to think that it is concerned in the *sense of taste*. On the other hand, it must be remembered that upon the tongue of the frog are very highly elaborate nerve organs of a special structure, which have a very large number of nerve-fibres distributed over a small space quite at the summit of the papilla ("Phil. Trans.," 1864). If, therefore, the frog possesses the sense of taste, the delicate papillæ above referred to are doubtless the organs concerned, and not the general surface of the palate, the nerves distributed to which probably take part in general sensation only.

They may be concerned in general sensation.—The nerve fibres distributed to the capillary vessels pro-

bably in all cases take part in what may be called general sensation. It is through the agency of the beautiful little "tactile corpuscles" in the papillæ of the skin that we are able to distinguish those very slight differences of quality in fabrics when the tip of the finger is gently drawn across them. But if every tactile corpuscle were destroyed, we should still be able to *feel*, and the skin of the finger would still be differently acted upon by hot things and cold things. The same sort of reasoning, justifies the supposition that the nerves which I have shown are distributed to the capillaries of voluntary muscle, act as sensitive fibres, and are perhaps concerned in conveying to us the sensation by which we are enabled to form a conception of the exact degree of contraction which has been effected in the muscle under different circumstances. And in certain forms of disease in which there is no loss in the power of contracting the muscle, but in which the mind does not form an accurate idea of the degree of contraction which has been induced, it is probable that these nerve fibres, or the centres with which they are connected, are the particular parts of the nervous system which are involved. The cold feeling, the chill and shivering which precede a cold or an attack of fever, result, I believe, from a change brought about in these fibres distributed to the capillaries, consequent upon disturbance in the capillary circulation, and the phenomena induced thereby just outside the minute vessels.

Their connection with ganglia.—Few questions are of higher importance than the determination of the relationship between the nerves distributed to the capillaries and those ramifying in such great number on and amongst the muscular fibre cells of the small arteries which divide into the branches from which the capillary vessels spring. Now, I can adduce direct anatomical observations in favour of the view

which I have been led to accept. In the frog I have succeeded in actually tracing nerve fibres from a ganglion to a nerve trunk, and from the trunk to the capillary vessels; and in the bladder of the frog I have been able to follow fine nerve fibres from the ganglion both to arteries and capillary vessels. It is surely justifiable to infer that a similar disposition exists in the higher vertebrata and in man. Such an inference is, however, almost irresistible if we bear in mind the vast number of ganglia existing in the submucous areolar tissue of the intestinal canal and the course taken by the nerve fibres from these, and the fact of the great alteration frequently taking place in the vascular turgescence of the mucous membrane. But, further, there are certain physiological experiments which have a most important bearing upon the question under discussion, and to which I will direct the reader's attention.

Physiological Experiments.—Many years ago when I possessed two living specimens of the Proteus, which I brought home from the cave at Adelsberg, I often observed the change which instantly took place when a bright ray of light was suddenly thrown upon the vessels of the exposed branchiæ. The little arteries of the gill suddenly contracted, and the entire volume of the vascular tuft was reduced by at least one-third. The circulation through the vessels was instantly retarded, the diameter of the capillaries was sensibly reduced, and the flow of the blood stream distinctly checked. The ray of light, I conclude, acted directly upon certain nerve fibres distributed around the capillaries, and an impression being carried to the nerve centre, the muscular fibre cells of the artery were made to contract through the vaso-motor nerves which are connected with the same nerve centre.

Another experiment which may be easily tried upon the web of the foot of the living frog is almost as conclusive, although it is open to the objection that

the fibres which carry the impression to the nerve centre are not those of the capillary vessels, but the sensitive fibres distributed to the cutaneous surface. It must, however, be remembered that there are no special tactile organs in the part of the web experimented upon, and that the capillary vessels with their nerve fibres lie immediately beneath the thin cuticular covering of the web.

The experiment is performed as follows:—The foot of a young living frog is well arranged for observation and covered with thin glass, so that the circulation in the vessels can be well studied with a quarter of an inch object-glass. The illumination must be good. The tube of the microscope is then lengthened by ten or twelve inches. By this proceeding we greatly augment the magnifying power. Next, a small artery is brought well into the field of the microscope, and carefully focussed. While the observer is looking intently at the artery the surface of the web near the spot under examination is very gently touched with the point of a needle, which should have been already mounted in a handle made of a piece of light wood.* Instantly the artery begins to contract, and in a few seconds its cavity is so narrowed that not a single blood corpuscle can pass. The contraction is not quite even, for the outlines of the vessel appear more or less wavy. After a few seconds an undulatory movement of the coats is noticed, and the artery gradually dilates to the same degree as before the irritation of the web.

The results of these experiments, considered in connection with the facts discovered by careful anatomical investigation, prove, I think, conclusively the function of the fine nerves distributed to the capillary vessels, and indicate the precise manner in which they act. These fibres must be afferent and carry

* The experiment often succeeds when the most distant parts of the web are touched.

impressions to the nerve centres from which the efferent or motor branches distributed to the coats of the arteries spring. In many tissues and organs in which the circulation is easily disturbed by peripheral irritation the nerve fibres distributed to capillary vessels are exceedingly numerous.

311. Of the self-acting mechanism by which the supply of blood to tissues is regulated.—We are now in a position to consider the probable arrangement of the reflex nerve mechanism by which the flow of blood in the capillaries is regulated, and the equable distribution of nutrient fluid to the tissues outside the capillaries is ensured in a state of health. We shall also see how this elaborate mechanism is rendered self-acting, self-regulating, and self-adjusting during the healthy state.

As is well known, the nutritive operations of man and most vertebrata have to be carried on with comparatively little alteration under *very variable and continually changing external conditions.* A limited range of variation is permitted, but if the limits within which this self-adjusting apparatus acts perfectly, be overstepped in either direction, as not unfrequently happens under the very variable and artificial conditions to which civilised man and domestic animals are exposed, the range of the capacity for self-adjustment is exceeded, the mechanism is strained, and a part temporarily thrown out of order, or seriously damaged. Unfortunately repair can only be imperfectly carried out, and the arrangement restored to its normal state in cases in which the injury is comparatively slight. So complex is the mechanism and so widely distributed are its interdependent parts that renovation after its destruction is complete is impossible, and I doubt of its re-formation in the adult has ever occurred, or is indeed possible.

In the diagram in Plate XXI. I have collected and arranged the facts ascertained by anatomical investi-

gation, and have represented the several parts of which the self-regulating mechanism is, I believe, made up. I have also indicated what I believe to be their true relationship. By reference to the plan the reader will observe that the artery *a* is surrounded by muscular fibre cells which are supposed to be contracted, and the capillaries near the artery over the figure 2 are also represented as they would appear when very little blood was traversing them; while those to the left of the drawing, over figure 1, are as they would appear if distended with blood. It is obvious that in the first case an interval would exist between the nerve fibres and the capillary vessels, while in the latter, where the capillaries are distended, the external surface of their walls would be almost in contact with the nerve fibres and the particles of bioplasm connected with them. A dark line on each side of the artery indicates the diameter of the vessel when its walls are relaxed, and similar dark lines within the dilated portion of the capillary vessels, over figure 1, show the diameter attained by these vessels when the flow of blood through the artery is checked by the contraction of its muscular coat.

Such an arrangement as that represented we should find would act as a self-regulating mechanism of the most perfect kind. Suppose for a moment a tissue is receiving more nutriment than it appropriates, the capillary nerve fibre will be at once disturbed, a change instantly transmitted to the nerve centre, and the efferent nerves distributed to the artery participating, the muscular fibres will contract. The arterial tube will be instantly narrowed, and less blood consequently sent to the tissue. In an opposite state the phenomena would be reversed—the arterial walls relaxed and the capillaries distended with blood. Or suppose that any noxious materials or living germs of any kind were making their way from with-

PLATE XXI.—MECHANISM GOVERNING THE DISTRIBUTION OF BLOOD IN THE CAPILLARIES.

Diagram to show self-regulating mechanism connected with the minute arteries and capillaries. *a*, artery with muscular fibre cells; the dark lines show its diameter when dilated. *b*, small vein. *c*, capillary network. Over No. 1 the capillaries are dilated, and over No. 2 they are contracted. *d* is a ganglion cell with at least two sets of nerve fibres connected with it, one of which, *e*, divides and subdivides, giving off nerve-fibres which are distributed to the artery *a*, while the other, *f*, is continuous with the plexus of nerve fibres ramifying close to the capillary vessels. Nerve fibres are also distributed to the small vein, *b*, but these are not represented in the drawing. The bioplasm of the vessels and nerve fibres is shown. p. 327.

out into the blood, it is obvious that if the nerve fibres distributed to the capillaries were healthy they would be instantly affected by the contact of the foreign body, and the vaso-motor nerves of the arteries would as instantly respond to the disturbance excited in the ganglion cell. The contraction of the arteries would follow, and the narrowing of the capillary vessels, and a corresponding increase in the thickness of their walls would result. This last condition would be likely to prevent, and would certainly retard, the ingress of particles to the blood. The foreign body thus kept from entering the current of the circulation might remain till it was destroyed or altered by the surrounding fluid, and thus rendered harmless, or, in the case of living matter, till its death had occurred. In this way it may be that the capillary nerves of a person in perfect health protect him and are directly instrumental in preventing the access to his blood of substances which are with great difficulty changed, or which must infallibly produce disease if they find their way into his circulating fluid. The fibres distributed to the capillaries are probably those which are irritated or paralyzed by certain substances which after being absorbed by the blood at one part of the system transude through the delicate walls of the vessels in other situations, and are thus brought into contact with the nerve fibres just outside the capillaries. These nerve fibres are, I believe, primarily affected in cases of sudden death resulting from the presence of certain poisons, such as hydrocyanic acid, and are I think influenced in the production of those slower changes which arise from poisonous matters of another kind being introduced into the blood.

312. Influence of the veins.—In regulating the flow of blood through the capillary vessels it must not, however, be forgotten that the veins perform an important part. By the reduction of the calibre

of the vein the circulation of the blood in the capillaries would be retarded; and as a given degree of contraction of the muscular fibre cells can be preserved for a certain period of time, it is clear that the veins share with the little arteries the office of regulating the flow of blood through the capillaries, and form an important part of that mechanism through the instrumentality of which the distribution of blood to the tissues and organs of man and the higher animals is constantly regulated and controlled. By the contraction of the muscular fibres of the small veins the lateral pressure of the blood upon the capillary walls may be altered from time to time, and the rapidity with which the blood traverses the capillaries made to vary.

The smallest veins, like the capillaries, are destitute of muscular parietes, but are remarkable for the great number of oval bioplasts connected with their coats and projecting into the interior of the vessel. In many of the smaller veins the united area of the bioplasts would considerably exceed that of the membranous portion of the wall of the vein. Fig. 2, Plate XV, page 293. These bioplasts are the agents concerned in the absorption of nutrient constituents from the blood and their distribution in an altered form to the tissues. It is these bodies which, by removing and taking up certain of the substances dissolved in it, promote the onward flow of the blood. Thus, as has been already stated, the *vis-à-fronte* action may be accounted for and explained. If, from any circumstances, these bioplasts do not act properly, the blood flows through the veins at a slower rate, unless the force with which it is propelled is increased.

313. Action of the nerve-fibres of the capillary vessels in inflammation.—It is scarcely possible that nerve-fibres lying very close to the capillary walls should be uninfluenced when the volume of blood in

the capillary is increased, as in congestion. By the long-continued stretching or pressure to which these delicate nerve-fibres would be subjected, partial paralysis would be induced.

In inflammations and in the long-continued feverish condition, the growth of bioplasm external to the vessels, and which results from the multiplication of bioplasts that had traversed the capillary walls during the stage of congestion, must seriously impair the action of these nerve-fibres; and there is good reason to think that some of the phenomena that ensue are the direct consequence of the nerve disturbance. Let us, therefore, consider very briefly the changes occurring in one of the slightest and most familiar forms of inflammation—a common flea-bite.

The tissues which are perforated by the cutting instrument of the flea as it penetrates, would be, first, the epithelium; next, that modified connective tissue with its "corpuscles" (masses of bioplasm) of which the papillæ and the most superficial layer of the true skin consist. Embedded in this connective tissue are certain vessels and nerves. The following tissues would be more or less damaged by the passage of any sharp instrument through the different layers of the skin,—cuticle, connective tissue, the capillary vessels (lymphatics in some instances), and nerves: and these are the only tissues which can be affected under the circumstances alluded to. Now the capillaries, as we know, receive blood from the arteries; and the calibre of the latter vessels, and therefore, the quantity of blood traversing them and the capillaries, is determined by the state of the nerves which supply them, and the nerve centres.

Now, it will be noticed in a flea-bite or other inflammation of skin, that there is a certain blush which is very deep in colour close to the wound, but paler in tint extends a considerable distance around

the point actually injured. This inflammatory blush too, as can be easily proved, may be completely removed by pressure. If I press the skin, the tint of the portion inflamed will become pallid and of precisely the same hue as the surrounding healthy skin. When I withdraw the pressure, and the blood is permitted to return, the pallor is gone and the capillaries of the normal skin are distended to precisely the same calibre as before; the dilated vessels in the seat of inflammation are again dilated, and to precisely the same degree as before the blood was pressed from them. This simple experiment proves not only that there exists some mechanism by which the calibre of the vessels may be not only increased and reduced so as to allow a larger or smaller quantity of blood to flow through the capillaries in a given time, but that the increased quantity of blood which traverses these tubes in inflammation is determined and regulated by the degree of contraction maintained by the muscular fibre-cells of the small arteries. The particular state of contraction can be kept up only through the instrumentality of nerves and nerve-centres in which a certain temporary change has been established and is maintained for a time. Such an arrangement as that described in page 327, would enable us to explain the facts above referred to.

In the early stages of inflammation probably more blood actually flows through the capillaries of the inflamed part than through those of the healthy tissues; but after a time, as is well known, the circulation becomes slower, the capillaries are distended, and at last the blood ceases to flow. The self-regulating mechanism fails to act, and, unless relief speedily follows, may be destroyed.

Inflammation, as it occurs in the tissues of the higher animals is an exceedingly complex process, in which vessels, nerves, and many other structures take part. But changes are also occurring during in-

flammation which produce an influence upon the nerve-fibres outside the capillary vessels in an indirect manner. If the inflammatory change is not quickly succeeded by a return to the normal state, partial or complete paralysis of the little arteries results; the capillaries necessarily become distended, and their walls so attenuated, that the passage of fluids through them from the blood is very much facilitated. There is increased *exudation*. Now the *exudation* that escapes is not simply a clear fluid from which particles are deposited after the manner of crystals, and aggregated so as to form "cells," but at the time it is poured out there are suspended in it numerous living particles. These particles are found in considerable number, and are probably composed of matter like that which enters into the composition of the white-blood corpuscle. Moreover, the small particles detached from the white-blood corpuscles make their way through the capillary walls, and divide, and subdivide, and give rise in a short time to multitudes of minute bioplasts which can only be distinguished by the aid of very high magnifying powers. This was referred to in a paper which was presented to the Microscopical Society, in 1863, and published in the "Transactions." In many cases where the capillary vessels are distended, living particles of bioplasm pass through. These being surrounded with nutrient matter, grow, and divide, and subdivide very freely, and in this way are produced the multitudes of bioplasts commonly found immediately surrounding the capillary vessels in the earlier periods of inflammation of complex textures. Wherever fluid in which are suspended living particles stagnates, the conditions are favourable for the absorption by the living bioplasts of an increased quantity of nutrient material. Not only may this increased absorption of nutrient material occur outside capillary vessels, but it may proceed in the sub-

stance of a blood-clot. The white-blood corpuscles entangled in the clot have been known to multiply to such an extent as to give rise to the formation of multitudes of bioplasts which form a soft pale semi-fluid mass, exactly resembling a drop of pus. Pus, indeed, has been formed in a clot of fibrine. It is possible, that under some circumstances, pus may be formed in a clot of blood.

In this way I would venture to explain also the changes which ensue in the serous or fibrinous exudation which occurs in the inflammation of certain special tissues. As is well known, serous membranes are subject to what is known as adhesive inflammation, which is described by some pathologists as if it were distinct from the suppurative. But pus may be formed upon the surface of a serous membrane. When we consider the structure of the serous membrane, and bear in mind how exceedingly thin it is, and how close the vessels are to its free surface, it is easy to conceive that minute particles of bioplasm would pass through, collect upon the free surface, grow and multiply, and give rise to the enormous quantity of fibrinous material frequently seen, for example, upon the surface of the pleura and pericardium in inflammation. In this way is probably produced the "recent lymph." We know, however, that pus may be formed if the process goes on. As nutrition increases, the little bioplasts multiply exceedingly; the "lymph" is found to consist almost entirely of bioplasts, which even take up the fibrinous matter, as well as soluble nutrient substances by which they are surrounded, and at last "pus," which, as I have shown, consists of multitudes of rapidly-growing living bioplasts, results.

It is not possible that such changes as those described could take place just outside capillary vessels without seriously implicating the nerves themselves, leading thereby to disturbance of the nerve centres,

and by reflex action to the extensive and widely-distributed nervous derangement which usually attends serious inflammations and general fevers. In both classes of diseases the characteristic general disturbance is due entirely to changes in the capillary vessels and in the nerves of the capillary vessels, the arrangement of which has been described.

314. Alteration of nerve fibres and capillaries in chronic disease.—The condition of *health* is dependent upon the integrity of the nerve fibres distributed to the capillary vessels. It is therefore of the utmost importance to do all we can to keep these delicate nerve fibres in an active state. By exercise, cold bathing, and external rubbing, that amount of activity of the nerve fibres and change in the capillary circulation is ensured at least once in the twenty-four hours that is required for keeping the nerve mechanism which has been described in good order and activity. These nerve fibres are, as it were, the sentinels which give the earliest information of the dangerous proximity to the vessels of matters the entrance of which into the blood might occasion serious disease or cause death. So long as these sentinels are active and in good working order, warning is given in time for the performance of acts which prevent the ingress of deleterious substances; but if they act sluggishly, or if the excitability of these nerve fibres is numbed by certain agents, time is allowed for the poison just outside the vessels to make its way into the blood: while if they are paralysed, even temporarily, the state of things is far worse. No watch is kept, and the organism may be destroyed by an invading poison that under other circumstances might have been effectually excluded.

In many forms of chronic disease the nerve fibres distributed to the capillary vessels, as well as those ramifying upon the small arteries and veins, degenerate and are at length destroyed. So that the

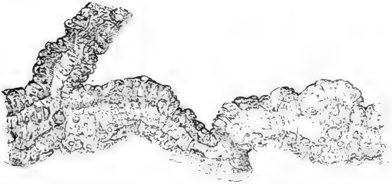
variations in vascular tension and blood distribution which occur in the healthy state through the agency of these nerves cannot take place. If, therefore, in consequence of the body being exposed to very adverse conditions the circulation be much disturbed, the derangement cannot be compensated or the injury repaired. It too often happens, indeed, that the damage progressively increases until sufficiently great to render a fatal result inevitable.

In fatty degeneration of the capillary vessels and small arteries, the fine nerve fibres are also involved, and the mechanism for regulating the flow of blood through them is gradually impaired. In some cases the nerve fibres and the muscular fibres of the arterial coats have so completely degenerated that the distribution of blood is greatly impeded. The outline of the vessels becomes uneven, their coats thicker in some places than in others, and the lining membrane rough. The elasticity of the vascular walls is much impaired, and in not a few instances the tube is actually rigid. The nutrition of every organ in the body suffers partly from changes which act through the circulation of the blood, and in part from the altered composition of the blood itself, which is gradually induced by the deranged circulation occurring in the blood-forming and blood-changing organs.

The changes in the minute vessels are, I believe, for the most part brought about in this wise. From increased nutrition the bioplasts of the capillary walls increase in size and divide and subdivide. (See "Disease Germs," 2nd edition, page 218,) Plate XXII, figs. 1, 2. Again, owing to the dilitation of the capillaries and thinning of their walls, particles of bioplasm escape from the blood and accumulate outside the capillary wall. These grow and multiply, and give rise to bioplasts from which connective tissue may be formed, or which after a time may die, and

PLATE XXII.—COATS OF ARTERIES ALTERED BY DISEASE.

Fig. 1.



Artery from a diseased kidney, showing great irregularity of calibre and degenerated muscular coat. The walls of the vessel have probably completely lost their contractile power. Oil globules and debris are seen in the interior. × [illegible] p. [illegible]

Fig. 2.

A transverse section of a small artery from the same kidney as Fig. 1. × 215 p. [illegible]

Fig. 3.

Artery from the peritoneum of a frog which had been kept for some time without food, showing wasting of muscular fibre cells and great diminution in calibre. In its present wasted and contracted state, the external areolar coat is many times the diameter of the vessel. × 215.

give rise to products which cannot be readily absorbed, and which as they accumulate will seriously interfere with the operations connected with nutrition and impede the flow of nutrient fluid from the blood to the adjacent tissues, as well as prevent the return to the blood of the products of decay. We see, then, that the structural alterations are consequent upon changes occurring in bioplasm. The bioplasm itself would not have been in the situation indicated if the normal action of the capillaries, arteries, and veins had been maintained and controlled by the self-regulating mechanism which has been described.

The deterioration in structure of the coats of the larger vessels is also due to an abnormal growth of bioplasm, depending probably upon a previous change in the composition of the nutrient fluid by which their coats are permeated.

The deposition of the so-called "atheromatous" material in the wall of the artery is due to changes consequent upon the presence of bioplasm in undue proportion at a much earlier period. Bioplasts grow and multiply in the substance of the arterial coats. By the increase of these collections the layers of elastic and muscular tissue are separated from one another. In consequence the tissue deteriorates. After a time the bioplasts die. Of the substances resulting from their death some are absorbed, but others, such as the fatty matter and calcareous salts remain behind and accumulate, constituting the hard or soft matter which is found in the substance of the arterial walls in cases of very long-standing disease. Such are some of the remarkable alterations which take place in the walls of arteries, and not commonly precede rupture and the occurrence of aneurismal dilatations in the case of the largest vessels. Changes of the same character affecting the smaller arteries and capillaries invariably lead to serious derangement of

the nutritive operations, and eventually to irreparable structural alteration in the tissues in which they ramify. A number of fatal diseases originate in changes in the vessels, and in many cases it is almost certain that the change in the wall of the vessel is indirectly due to an altered state of the blood, which may have been caused by injudicious living as regards the quantity and quality of solids or liquids swallowed.

List of Microscopical Specimens illustrating Lecture XII.

No.		No. of diameters magnified.
128.	Frog's foot, showing arteries, veins, and capillaries injected	40
129.	Bladder of frog, showing arteries, veins, and capillaries, injected with prussian blue	130
130.	Capillaries of pia mater injected with prussian blue.	130
131.	Capillaries of retina. Ox injected with prussian blue	130
132.	Capillaries of lung	130
	,, liver	130
	,, kidney	130
133.	Malpighian bodies, showing afferent and efferent vessels	130
134.	Capillaries of villus	130
135.	,, large intestine	130
136.	Capillaries of the margin of the cornea, showing mode of development, injected with prussian blue —Guinea-pig..	210
137.	Capillaries of striped muscle—Frog..	130
138.	Capillaries of nerve—Frog	130
139.	Capillaries of pia mater, injected with pale prussian blue, showing thin transparent wall	700
140.	Capillaries of ciliary processes of eye, showing transparent walls, with numerous bioplasts	220
141.	Bioplasts of arteries, veins, and capillaries, coloured by carmine fluid—Pia mater, lamb	130
142.	Bioplasts, of capillaries, of nerves to capillaries, of connective tissue, and of fat cells—Frog.. ..	215
144.	Bioplasts of capillary vessels, well coloured by carmine—Pia mater lamb	500

No.		No. of diameters magnified.
145.	Elastic tissue of large artery	220
146.	Triangular muscular fibre cells—Aorta human subject	220
147.	Elastic tissue of veins..	220
148.	Striated muscular tissue of cava near auricle—Frog	220
149.	Large arteries, frog, showing ganglia and trunks of nerve-fibres in great number	40
150.	Small artery of frog, showing muscular fibres and numerous nerve-fibres distributed in the connective tissue around	220
151.	Nerve-fibres distributed to muscular fibre-cells—Small artery frog. With the aid of a high power, $\frac{1}{12}$, some of the finest ramifications of the nerve-fibres may be traced amongst the muscular fibre-cells	220
152.	Nerve-fibres ramifying in the areolar coat of a very small artery—Frog	220
153.	Nerves distributed to arteries, veins, and capillaries of bat's-wing	220
154.	Dark-bordered nerve-trunks and branches to capillary vessels, which run parallel to the vessel, and are connected at intervals by communicating branches. See Plate XIX, page 315. In this specimen fine nerve-fibres can be traced from trunks consisting of five or six fine dark-bordered nerve-fibres, and followed to the capillary vessels. From the connective tissue covering part of the mylo-hyoid muscle of the hyla or green-tree frog ..	215
155.	Part of same specimen showing nerve-fibres ramifying close to capillaries	700
156.	Fine nerve-fibres distributed to the cornea. Hyla. In this specimen numerous networks of extremely fine nerve-fibres are seen in the substance of the corneal tissue. Most of the masses of germinal matter in every part of the field belong to the corneal tissue, and are the so-called connective tissue corpuscles, but oval masses of bioplasm are also seen in connection with the nerve-fibres. The nerves are not continuous with the branches of the connective tissue corpuscles as Kühne supposed, nor do they give off numerous branches to the epithelium of the conjunctiva, as recently stated by Cohnheim	220

No. | No. of diameters magnified.

157. Division and branching of fine nerve trunks, and distribution of fine pale fibres to capillary vessel. The portion of the specimen under the microscope is in an interval between two portions of a muscle (voluntary) from the neck 220

Part of this preparation is represented in Plate XIX, fig. 1. In this and several other specimens, the fact of the existence of nerves to the capillary vessels is positively demonstrated. I have elsewhere adduced reasons for concluding that these with the fine nerve-fibres ramifying in the proper tissue of the cornea and other fibrous textures, those around the uriniferous tubes and various gland follicles, &c., constitute the afferent portion of the system, to which belong, as efferent branches, the so-called *vaso motor nerves* distributed to the arteries. These two sets of fibres with the ganglia common to both, constitute the *self-regulating mechanism*, by which in health the equable flow of nutrient matter to the various tissues and organs of the body is maintained, and through which any temporary disturbances are at once corrected or compensated for. Anatomical observation does not justify the conclusion so generally accepted, that there is a special system of nerves presiding in some mysterious way over the actual processes of nutrition and change, going on in each individual cell. And many of the facts taught us by experiments on living animals receive a more satisfactory explanation upon the view here advanced. For instance, there is the interesting observation on the foot of the living frog recorded in page 325.

158. Experiment. The frog's foot arranged as to show the circulation small artery is to brought into the field of the microscope. By gently touching the surface of the skin, even at a considerable distance from the point where the small artery is situated, it may be made to contract violently. In this experiment, the afferent fibres are irritated, an impression is carried to the nerve centre, and by the disturbance produced the efferent fibres are excited, and contraction of the artery results 215

159. Fine nerve-fibres distributed to capillary vessels of the palate of the frog forming networks and

No.		No. of diameters magnified.
	plexuses of fine fibres, many of which are less than the $\frac{1}{100000}$ of an inch in diameter	220
160.	Fine nerve fibres distributed to capillary vessels of papilla of the tongue of the hyla, or green-tree frog	700
161.	Fine nerve fibres distributed to capillary vessels of the peritoneum of the frog	220
162.	Capillary vessels and nerve-fibres from the tip of the mole's nose	220
163.	Very fine nerve-fibres distributed to the capillary vessels of the bat's wing	220
164.	Another specimen, showing capillaries and nerve-fibres of bat's wing	700

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